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ANALYSIS OF GLOBAL SOLAR RADIATION IN UYO, AKWA IBOM STATE, NIGERIA USING TEMPERATURE MODELS

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ABSTRACT

The monthly mean daily data for the global solar radiation, temperature (maximum, minimum and mean) for fourteen years (2000-2013) for Uyo, Akwa Ibom State, Nigeria have been used to develop an Angstrom-Prescott-type model for both linear, quadratic and cubic models. The value of the global solar radiation predicted by the models and the measured global solar radiation were tested using Mean Bias Error (MBE), Root Mean Square Error (RMSE) and the Mean Percentage Error (MPE) statistical techniques. The values of the correlation coefficient (R) and coefficient of determination (R^2) were also determined for each of the equations. The equations with the highest value of R, R^2 and the least values of MBE, RMSE, and MPE were recommended for use in estimating the global solar radiation in the locations.

INTRODUCTION

Solar energy is the world's most abundant source of energy. Burari and Sambo (2001) observed that the amount of insulation received by the surface of the earth per minute is greater than the energy utilization by the entire population in one year. Solar radiation while passing through the earth's atmosphere is subject to mechanism of atmospheric scattering and absorption. The scattering depends on the incoming radiation and the size of the scattering particles or gas molecules. A fraction of radiation reaching the earth's surface is reflected back into the atmosphere and is subjected to these atmospheric phenomena again; the remainder is absorbed by the earth's surface. The interaction of insulation particularly with clouds leads to variation in intensity of sunshine and the number of sunshine hours at the ground level thereby reducing the temperature (Ugwu and Ugwarnyi, 2011). Solar radiation data is an important component in determining the solar energy capability of a particular place. Meteorological data are used to correlate and develop models that can estimate global solar radiation in most of the places. Many such correlations exit for most town in Nigeria (Burari and Sambo, 2001, Ekpe and Nnabuchi, 2012, Umoh, *et. al,* (2013), Okonkwo and Nwokoye, 2014 and Akpan and Osu, 2015).

This paper seeks to develop another predictive technique using only temperature as the predictive factor for estimation of global solar radiation. The successful development of reliable models from temperature only will be of great advantage for the accessibility of global solar radiation data for solar energy needs of the nation. This study was done for Uyo, Akwa Ibom State, Nigeria. Uyo is located in the southern part of Nigeria. It lies on lat.5.05^0 N and long. 7.93^0 E with an elevation of 45m above the sea level.

MATERIALS AND METHOD

The monthly average global solar radiation, maximum, minimum and mean temperatures for the period of fourteen years (2000-2013) were obtained from Nigeria Meteorological (NIMET), centre Lagos. The mean extraterrestrial solar radiation H_o was calculated using equation given by Duffie and Beckman (1991). The solar radiation values obtained using Gunn-Bellani radiation integrators were converted to $MJm^{-2}day^{-1}$ using a factor of 1.216 as proposed by Ododo (1994). Values for monthly average extraterrestrial global radiation H_o were calculated for the fifteenth Julian day of each month. The processed data (H_m, H_o and temperature data), were used to form Angstrom-Prescott type correlation models (Angstrom, 1924) for analyzing global solar radiation on a horizontal surface for Uyo, Nigeria. The mean extraterrestrial solar radiation H_o is given by;

$$H_o = \frac{24}{\pi} I_{sc} E_o \left(\frac{\pi}{180} W_s \sin \phi \sin \partial + \cos \phi \cos \partial \sin W_s \right) \quad (1)$$

where I_{sc} is the solar constant in ($MJm^{-2}\,day^{-1}$), expressed as

$$I_{sc} = \frac{1367 \times 3600}{1000000}\, MJm^{-2} day^{-1} \quad (2)$$

E_o is the eccentricity correlation factor expressed as

$$E_o = 1 + 0.033 \cos \left(\frac{360d}{365} \right) \quad (3)$$

W_s is the hour angle expressed as

$$W_s = \cos^{-1} (-\tan\phi \tan\partial) \quad (4)$$

where ϕ and ∂ are the latitude and declination angles respectively.

$$\partial = 23.45 \sin \left(360 \left(\frac{d+284}{365} \right) \right) \quad (5)$$

where d is the Julian day.

The Regression coefficients (R) and the coefficient of determination (R^2) were obtained using appropriate correlation statistics. The Root Mean Square Error (RMSE); the Mean Bias Error (MBE) and Mean Percentage Error (MPE) for each of the models were obtained.

The expression for MBE, RMSE and MPE as stated by Almorox *et al* [2005] are

$$MBE = \frac{\sum (H_{ical} - H_{imeans})^2}{n} \quad (6)$$

$$RMSE = \left[\frac{\sum (H_{ical} - H_{imeans})^2}{n} \right]^{\frac{1}{2}} \quad (7)$$

$$MPE = \left| \frac{\left[\sum \left(\frac{H_{imeans} - H_{ical}}{H_{imeans}} \right) X\, 100 \right]}{n} \right| \quad (8)$$

where H_{ical} and H_{imeas} are the ith calculated and measured values for average months global solar radiation and n is the total number of observations.

MBE provides information on the long-term performance of models. A positive and a negative value of MBE indicate the average amount of over estimation and under estimation in the calculated values respectively. RMSE provides information on short-term performance of the model. MPE test provides information on long term performance of the examined regression equation. It is recommended that a zero value for MBE is ideal while low RMSE and low MPE are desirable (Akpabio and Etuk, 2005; Almorox *et al*, 2005; Igbal, 1983; Chieamaka (2008); and Nwokoye and Ike, 2003). Different temperature models were considered in order to determine the models most appropriate to estimate the global solar radiation in a place that has similar meteorological parameters with Uyo, Nigeria. The following linear Angstrom-Prescott type model 11, Quadratic models, cubic models and Hargreaves' model 15 were considered.

$$\frac{H_m}{H_o} = a_1 + b_1\,\bar{T}_{max} \quad (9)$$

$$\frac{H_m}{H_o} = a_2 + b_2\,\bar{T}_{min} \quad (10)$$

$$\frac{H_m}{H_o} = a_3 + b_3\,\bar{T}_{mean} \quad (11)$$

$$\frac{H_m}{H_o} = a_4 + b_4\,\frac{T_{min}}{T_{max}} \quad (12)$$

$$\frac{H_m}{H_o} = a_5 + b_5\,\frac{T_{mean}}{T_{max}} \quad (13)$$

$$\frac{H_m}{H_o} = a_6 + b_6\bar{T}_{min} + C_6\bar{T}_{max} \quad (14)$$

$$\frac{H_m}{H_o} = a_7 + b_7\bar{T}_{min} + C_7\bar{T}_{max} + d_7\bar{T}_{mean} \quad (15)$$

$$\frac{H_m}{H_o} = a_8 + b_8\bar{T}_{min} + C_8\,(\bar{T}_{min})^2 \quad (16)$$

$$\frac{H_m}{H_o} = a_9 + b_9\bar{T}_{min} + C_9\,(\bar{T}_{mean})^2 \quad (17)$$

$$\frac{H_m}{H_o} = a_{10} + b_{10}\,\frac{T_{min}}{T_{max}} + c_{10}\left(\frac{T_{min}}{T_{max}}\right)^2 \quad (18)$$

$$\frac{H_m}{H_o} = a_{11} + b_{11}\,\frac{T_{mean}}{T_{max}} + c_{10}\left(\frac{T_{mean}}{T_{max}}\right)^2 \quad (19)$$

$$\frac{H_m}{H_o} = a_{12} + b_{12}\left(\frac{T_{min}}{T_{max}}\right) + c_{12}\left(\frac{T_{min}}{T_{max}}\right)^2 + d_{12}\left(\frac{T_{min}}{T_{max}}\right)^3 \quad (20)$$

$$\frac{H_m}{H_o} = a_{13} + b_{13}\,\frac{T_{mean}}{T_{max}} + c_{13}\left(\frac{T_{mean}}{T_{max}}\right)^2 + d_{13}\left(\frac{T_{mean}}{T_{max}}\right)^3 \quad (21)$$

The Hargreaves' model is given as

$$Hm = C\left(\sqrt{\bar{\bar{T}}\max - \bar{\bar{T}}min}\right)H_o \quad (22)$$

where C is the adjustment coefficient. The adjustment coefficient for Uyo was calculated to be 0.141.

RESULTS AND DISCUSSION

Table 1 shows the monthly mean global solar radiation (H_m), mean extraterrestrial radiation (H_o, clearness index ($K_t = H_m/H_o$), minimum and maximum temperatures for Uyo.

Table 1 Monthly mean daily solar radiation and temperature data for Uyo

Month	H_0 ($MJm^{-2}day^{-1}$)	Hm (MJm^{-2} day^{-1})	K_t	$\bar{\bar{T}}min$ (^0C)	$\bar{\bar{T}}max$ (^0C)	$\bar{\bar{T}}mean$ (^0C)	$\frac{\bar{\bar{T}}min}{\bar{\bar{T}}max}$	$\frac{\bar{\bar{T}}mean}{\bar{\bar{T}}max}$
Jan.	33.11	14.18	0.4283	22.66	33.74	28.2	0.6716	0.8358
Feb.	36.01	16.44	0.4565	23.94	34.79	29.28	0.6881	0.8416
Mar.	36.01	14.36	0.4565	23.94	34.79	29.28	0.2209	0.8605
Apr.	37.49	14.99	0.3998	23.96	32.65	28.31	0.7338	0.8671
May	36.30	14.64	0.4039	23.74	31.95	27.85	0.7430	0.8717
June	35.32	13.45	0.3801	23.35	30.73	27.04	0.7598	0.8799
July	35.65	11.55	0.3240	23.14	29.93	26.54	0.7731	0.8887
Aug.	37.08	10.56	0.2848	22.91	29.00	25.96	0.7900	0.8952
Sept.	37.25	14.27	0.3831	23.01	29.98	26.50	0.7675	0.8839
Oct.	36.14	14.84	0.4106	23.23	31.2	27.22	0.7446	0.8724
Nov.	34.23	16.30	0.4762	23.68	32.19	27.94	0.7356	0.8680
Dec.	33.42	15.16	0.4536	22.10	33.10	27.6	0.6677	0.8338

Linear and non linear (quadratic and cubic) Angstrom-Prescott- type equations and Hargreaves' model were computed using fourteen years data set of monthly mean global solar radiation and temperatures. The corresponding correlation equations were obtained. These are used as models for prediction of global solar radiation in Table 2.

Tables 3a and 3b show the comparison between the measured and predicted data for Uyo in terms of mean values, statistical errors, and coefficients of determination. The regression coefficients a,b,c and d are also given in the Table.

Table 2. Different temperature models for estimating global solar radiation

Model	Equation
1	$\frac{H_m}{H_o} = -0.344 + 0.023\,\bar{T}_{max}$
2	$\frac{H_m}{H_o} = 0.236 + 0.007\,\bar{T}_{min}$
3	$\frac{H_m}{H_o} = -0.626 + 0.037\bar{T}_{mean}$
4	$\frac{H_m}{H_o} = 1.163 - 1.043\,\frac{T_{min}}{T_{max}}$
5	$\frac{H_m}{H_o} = 0.949 - 0.701\,\frac{T_{mean}}{T_{max}}$
6	$\frac{H_m}{H_o} = 0.678 + 0.025\bar{T}_{min} - 0.013\bar{T}_{max}$
7	$\frac{H_m}{H_o} = 0.678 + 0.053\bar{T}_{min} - 0.021\bar{T}_{max} - 0.027\bar{T}_{mean}$
8	$\frac{H_m}{H_o} = 1.966 - 0.023\bar{T}_{mean} + 0.0015(\bar{T}_{mean})2$
9	$\frac{H_m}{H_o} = -0.713 + 4.510\,\frac{T_{min}}{T_{max}} - 4.3\,00\left(\frac{T_{min}}{T_{max}}\right)^2$
10	$\frac{H_m}{H_o} = -0.63 + 5.243\,\frac{T_{mean}}{T_{max}} + -4.566\left(\frac{T_{mean}}{T_{max}}\right)^2$
11	$\frac{H_m}{H_o} = 0.148 - 0.018\left(\frac{T_{min}}{T_{max}}\right) + 3.457\left(\frac{T_{min}}{T_{max}}\right)^2 - 2.533\left(\frac{T_{min}}{T_{max}}\right)^3$
12	$\frac{H_m}{H_o} = -0.121 + 5.584\,\frac{T_{mean}}{T_{max}} - 4.288\left(\frac{T_{mean}}{T_{max}}\right)^2 + 2.765\left(\frac{T_{mean}}{T_{max}}\right)^3$
13	$Hm = 0.14\left(\sqrt{\bar{T}max - \bar{T}min}\right)H_o$

From Table 1, it is observed that the highest and lowest mean maximum temperature for Uyo occurs in February and August with 34.97^{0}C and 29.00^{0}C respectively. Also the highest and lowest mean minimum temperature was found to be in February and December with 23.94^{0}C and 22.10^{0}C respectively. These values are expected since the month of February is characterized by bright sunshine and dry atmosphere, while the month of August and December that have the lowest maximum and minimum temperature are characterized by heavy rain and dusty weather respectively which greatly reduce the intensity of solar radiation as also observed by Ekpe and Nnabuchi (2012) .

On considering the measured global solar radiation from Tables 3a and 3b, the highest measured global solar radiation occurred in February with 16.44MJm^{-2}day^{-1} while the lowest measured global solar radiation occurred in August with 10.56 Jm^{-2}day^{-1}. Also, the predicted global solar radiation represented in Models 1 – 13 have the highest predicted value in February with values ranging from 15.92MJm^{-2}day^{-1} to 17.45MJm^{-2}day^{-1}. In Models 2 and 3, March has the highest predicted solar radiation while Model 8 has December with the highest of 15.0 MJm^{-2}day$^{-1.}$ The lowest predicted is obtained from Models 1,4,5,9 and 13. This occurs in August with values ranging from 11.3 MJm^{-2}day^{-1} to 13.1 MJm^{-2}day^{-1} In July, the predicted values from model 3, 6, 7, 10, 11 and 12 are quite low with values ranging from 10.17 MJm^{-2}day^{-1} to 12.50 MJm^{-2}day^{-1}. Models 1, 3, 6, and 9 has small level of underestimation with MBE ranging from -0.0001 for Model 5 to 0.0058 for Model 3 and slight overestimation is observed with Models 2, 7, 8, 11, 12 and 13 with MBE values between 0.0058 for Model 3 and 0.067 for Model 8.

Table 3a: Comparison of measured and predicted data for global solar radiation, statistical error indicators and correlation constant in Uyo, Nigeria (Models 1 – 7)

Months	Hm	Hp Model1	Hp Model2	Hp Model3	Hp Model4	Hp Mode5	Hp Model6	Hp Model7
JAN	14.18	14.30	13.07	13.82	15.31	15.72	14.52	14.76
FEB	16.44	16.43	14.53	16.47	16.04	17.45	16.77	16.03
MAR	14.36	16.09	15.21	16.66	15.42	16.93	16.19	15.39
APR	14.99	15.26	14.14	15.80	14.91	16.15	14.86	14.37
MAY	14.64	14.19	14.60	14.68	14.09	15.11	13.48	13.20
JUN	13.45	12.81	14.11	13.23	13.09	14.00	12.32	12.28
JUL	11.55	12.28	14.19	12.09	12.71	13.32	12.24	10.17
AUG	10.56	11.98	14.70	12.40	12.57	13.10	12.39	12.55
SEPT	14.27	12.87	14.80	13.21	13.50	14.02	13.58	13.95
OCT	14.04	13.50	14.41	13.77	13.96	14.60	14.73	14.73
NOV	16.30	13.57	13.75	13.96	13.55	14.48	15.76	15.76
DEC	15.16	13.87	13.06	13.21	15.59	15.58	15.26	15.26
Mean	14.16167	13.92917	14.21417	14.10833	14.22833	15.03833	14.34167	14.08167
Diff. (Hm-Hp)		0.2325	-0.0525	0.05333	-0.06667	-0.87667	-0.34167	0.08
MBE		-0.025	0.0058	-0.0058	-0.018	-0.0001	-.084	0.0092
RMSE		0.087	0.0202	0.0202	0.0635	0.0029	0.029	0.0315
MPE		0.175	-0.041	0.04	0.128	0.0006	-0.474	-0.187
R		0.65	0.079	0.682	0.546	0.617	0.755	0.897
R^2		0.57	0.096	0.465	0.298	0.381	0.570	0.805
a		-0.344	-0.236	-0.626	0.955	1.163	2.178	-0.074
b		0.023	0.007	0.037	-0.026	-1.043	2.054	-0.135
c								0.025
d								-0.145

Table 3b: Comparison of measured and predicted data for global solar radiation, statistical error indicators and correlation constant in Uyo (Models 8 -13)

Months	Hm	Hp Model8	Hp Model9	Hp Modell0	Hp Modell1	Hp Model12	Hargreaves' Model
JAN	14.18	13.55	15.27	14.72	14.01	14.76	15.04
FEB	16.44	14.10	16.18	16.72	15.97	16.68	15.84
MAR	14.36	14.00	15.42	16.05	15.38	15.10	14.93
APR	14.99	13.55	14.91	15.17	14.00	15.21	13.97
MAY	14.64	12.85	14.07	13.79	13.27	13.35	9.17
JUN	13.45	12.76	13.09	12.53	12.17	12.12	12.14
JUL	11.55	13.38	12.72	12.50	11.28	11.45	11.80
AUG	10.56	14.31	12.58	12.34	12.72	12.53	11.30
SEPT	14.27	14.76	13.50	13.79	13.19	13.87	12.68
OCT	14.04	14.89	13.95	14.94	14.28	14.79	13.85
NOV	16.30	14.94	13.53	15.94	16.27	15.77	13.58
DEC	15.16	15.00	15.55	15.39	15.17	15.47	15.18
Mean	14.16	14.00	14.230	14.49	13.97	14.25	13.29
Diff. (Hm – Hp		0.15416	-0.06917	-0.32833	0.185833	-0.09667	0.871667
MBE		0.0675	-0.0167	0.0267	0.0085	0.0065	0.066
RMSE		0.2338	0.057	0.087	0.0074	0.092	0.021
MPE		-0.117	-0.064	-0.231	-0.073	-0.067	-0.321
R		0.756	0.769	0.866	0.873	0.925	0.732
R^2		0.572	0.578	0.75	0.767	0.856	0.536
a		0.094	0.096	-0.982	0.148	-0.121	
b		0.011	0.012	3.548	-0.018	5.584	
c		-0.03	0.003	0.0013	3.457	-4.288	
d					2.533	-2.765	

It is be noted that for a good estimation, the MBE value of zero is desired (Akpabio and Etuk (2005). For future prediction reliability, Models 7, 10, 11 and 12 are preferred with R^2 of 0.805, 0.75, 0.766 and 0.856 respectively. Since closer to unity the value of R^2 is the more reliable the future predictability is (Akpan and Osu (2015).

Model 5 gives the smallest underestimation level with MBE of 0.0001, and best prediction level with RMSE of 0.0029. Though Model 12 has a low MBE value of 0.0065, its RMSE value of 0.092 makes this model less preferred to Model 11 with MBE of 0.0085 but with RMSE of 0.0074 for lower overestimation. Figures 1 to 13 show the monthly variation between the measured and predicted values for Uyo.

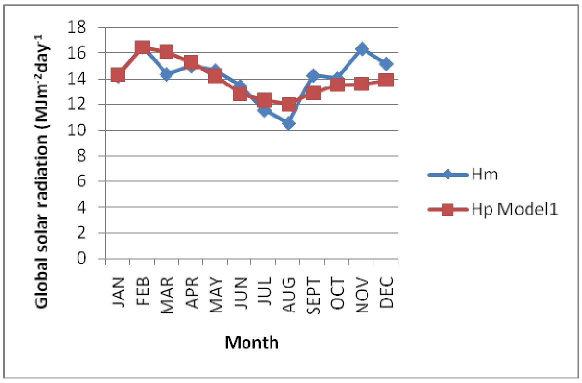

Figure1: Comparison of Measured and Predicted Global Solar Radiation in Uyo for Model 1

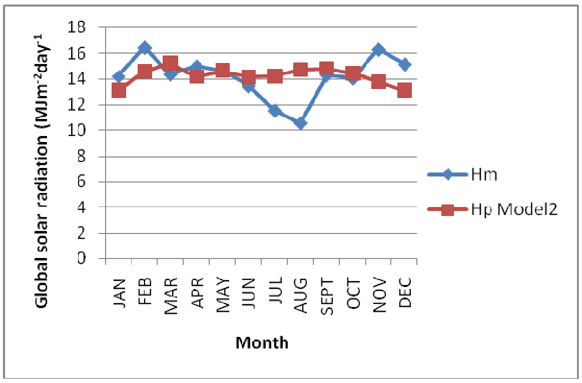

Figure 2: Comparison of Measured and Predicted Global Solar Radiation in Uyo for Model 2

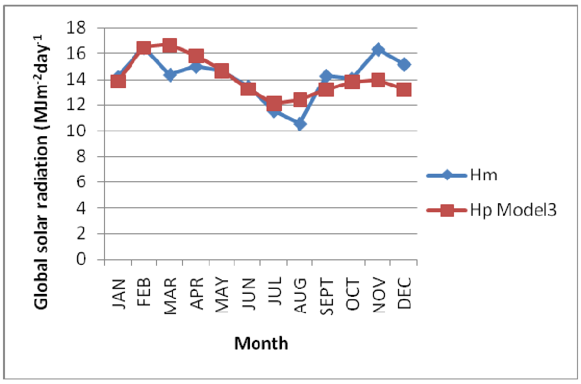

Figure 3: Comparison of Measured and Predicted Global Solar Radiation in Uyo for Model 3

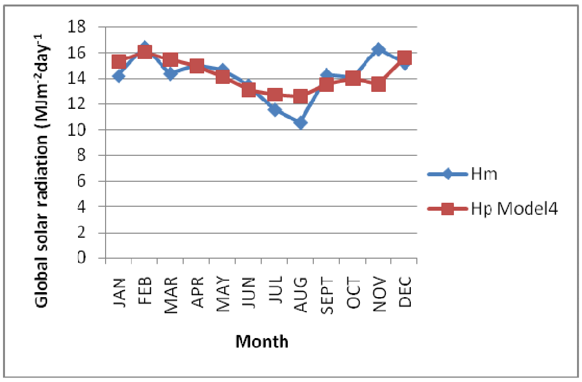

Figure 4: Comparison of Measured and Predicted Global Solar Radiation in Uyo for Model 4

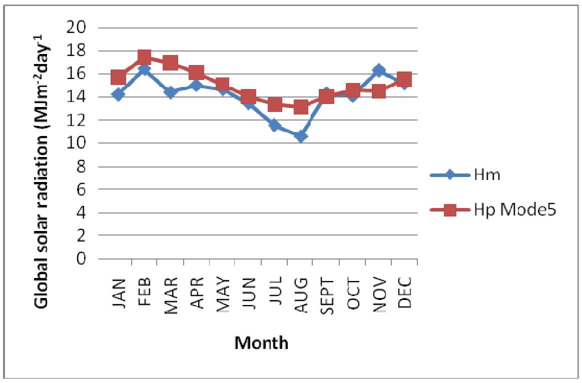

Figure 5: Comparison of Measured and Predicted Global Solar Radiation in Uyo for Model 5

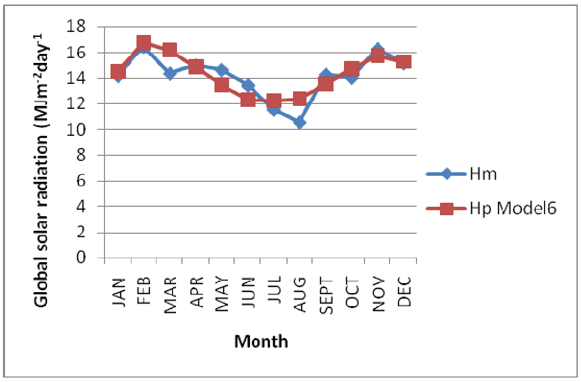

Figure 6: Comparison of Measured and Predicted Global Solar Radiation in Uyo for Model 6

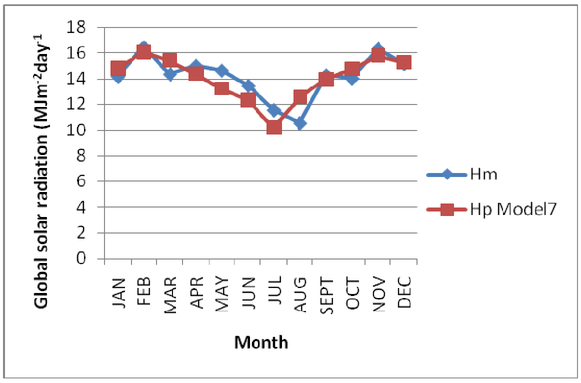

Figure 7: Comparison of Measured and Predicted Global Solar Radiation in Uyo for Model 7

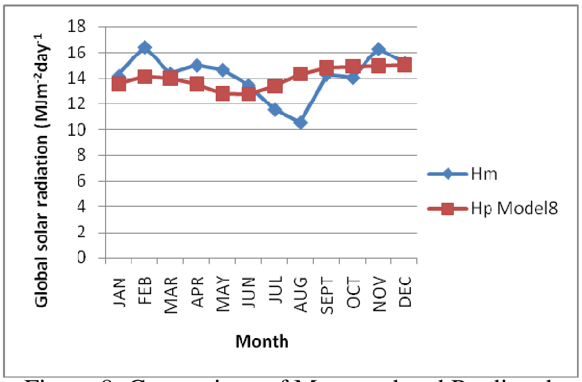

Figure 8: Comparison of Measured and Predicted Global Solar Radiation in Uyo for Model 8

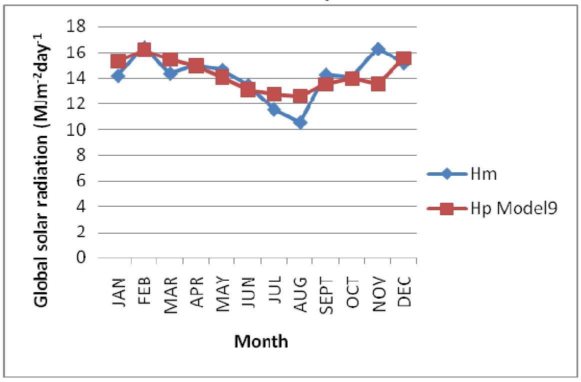

Figure 9: Comparison of Measured and Predicted Global Solar Radiation in Uyo for Model 9

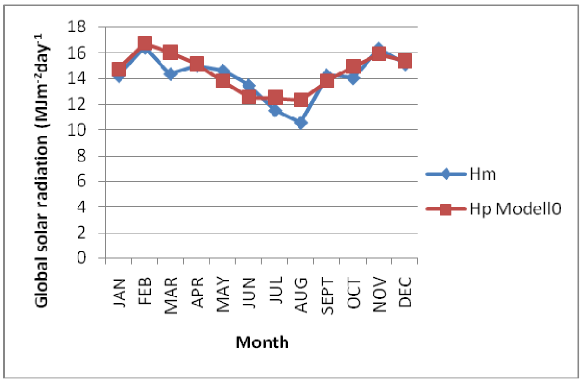

Figure 10: Comparison of Measured and Predicted Global Solar Radiation in Uyo for Model 10

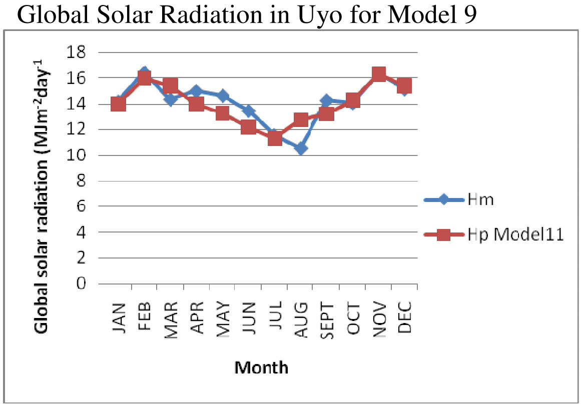

Figure 11: Comparison of Measured and Predicted Global Solar Radiation in Uyo for Model 11

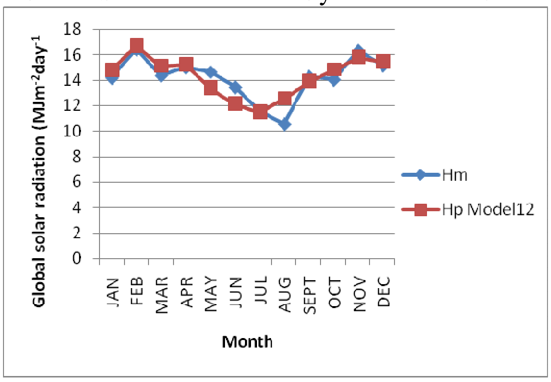

Figure 12: Comparison of Measured and Predicted Global Solar Radiation in Uyo for Model 12

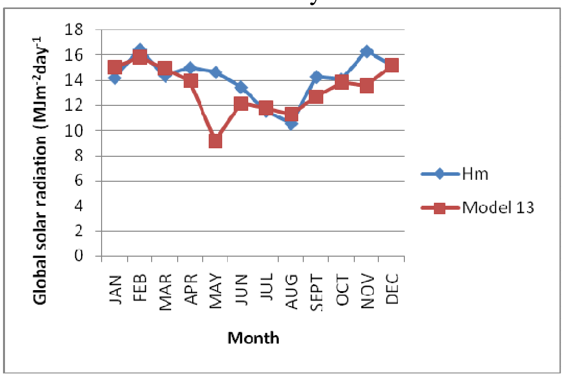

Figure 13 Comparison of Measured Global Solar Radiation with the Hargreaves' Model in Uyo

CONCLUSION

The monthly mean daily global solar radiation has been estimated using temperature as the only parameter to develop the Angstrom-Prescott type of equations. Thirteen different models using maximum, minimum and mean temperatures and their ratios have been developed. The results show that linear Models 5 and 7 give better estimation and prediction results. Quadratic Models 10,11 and 12 also give good prediction result.

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