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Temperature Based Models for Determining Solar Radiation in the Savannah Region

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ABSTRACT
Due to erratic power supply, effort towards the development of alternative energy system is increasing on a daily basis. The quantity of radiation is essential for efficient designing and selecting energy devices for agricultural, industrial, telecommunication and household uses. It requires knowledge of the actual solar radiation (SR) reaching the earth's surface at the location of interest. In this study, temperature-based methods to determine SR in the savannah region using Abuja (9.05^0N, 7.49^0E). Nigeria as a case study was conducted. Hargreaves-Samani, Annandale and Samani models were analyzed and compared with ten years data on SR, and temperatures from 2001 to 2010 from Nigerian Meteorological Agency, NIMET Abuja. The solar declination δ, eccentricity correction factor of the earth's orbit E_o, and day angle $\tau(^0)$ were determined to estimate extraterrestrial SR on a horizontal surface. The models were tested in terms of the mean bias error (MBE), root mean square error (RMSE) and the percentage RMSE. The results revealed Hargreaves-Samani is the most fitted followed by Annandale while Samani model is not applicable due to proximity to large water bodies. The extraterrestrial and SR continuously decreases during summer due to absorption, scattering, reflection and transmission by clouds, ozone layer, water vapour, carbon dioxide, smog and other particles while their values increases drastically during winter in agreement with other research findings.

Keywords:
Solar Radiation,
Estimation,
Hargreaves-Samani,
Annandale,
Samani,
Models.

INTRODUCTION

Renewable electricity refers to electric energy sources that is clean and is not depleting earth's resources with minimal environmental impacts and conserving hydro and biomass combustion. Due to erratic power supply, effort towards the development of alternative energy systems are on the increase. The need to estimate the quantity of solar radiation in the savanna region is essential. Solar energy is renewable and its utilization is environmentally friendly. The efficient utilization of SE for system design and selection of components for agricultural, industrial, telecommunications and household applications require knowledge of the actual solar radiation reaching the earth's surface at the locations of interest especially for the installation of photovoltaic and optoelectronic devices and materials having low thermal responses. SR and related meteorological parameters are needed in thermal loading on buildings and description of atmospheric phenomena, weather forecasting and prediction, aviation and air traffic controllers, scientific and economic uses (ICEED Nigeria, 2006; Ezekoye et al., 2011; Nwankwo et al., 2012).

SR in vegetative savannah is enormous and fairly distributed within the country. Based on the theoretical and experimental data, the annual average SR varies from 12.6 MJ/m^2/day in the coastal latitudes to about 25.2MJ/m^2/day in the far North (Abdul-Malik et al., 2009; Okoye et al., 2011; Nwankwo et al., 2012). If 0.1% of the total incident radiation at a conversion of 1% is utilized for power generation, we will have excess power. Solar appliances with 5% efficiency covering 1% of the entire lass mass of Nigeria in the savannah region produces 2.541 x 106 MWh of electricity (Ogunleye and Awogbemi, 2010). In a situation where radiation data is not available in any location within the savannah region, installing and taking accurate SR reading using pyranometer for at least a year before any solar equipment could be installed is cumbersome, costly and takes a very long time to get accurate information (Malgwi and Ladan, 2005).

Within the savannah region, some studies have been conducted. In 2008, Chiemeka reported on SR at Uturu, Abia State using temperature data in October 2007 and Hargreaves equation. It showed that the mean values varied from 1.89-0.82 KWh per day. Osueke et al., 2013 evaluated solar energy variation at Enugu, Lagos, Abuja and Maiduguri within the savannah using 22 years data from National Aeronautics and Space Administration (NASA). It indicated a linear conformity with correlation coefficients between 0.78 and 0.8, Abuja 0.546 and Enugu 0.004. Maiduguri experienced the greatest solar irradiance range of 5.5-6.7kWh/m^2/day except for the month of January, November, and December. Okundamiya et al. (2011) proposed multivariable model of the monthly mean daily diffuse SR at Abuja, Benin City and Katsina using a second-order polynomial method between diffuse and global SR. The study was done based on a correlation between clearance index (CC) and diffuse to global SR ratio. It revealed that the techniques could be used to predict the quantity of the SR in the selected locations. In 2012 at Port Harcourt, Ainah et al., presented Duffie and Beckman technique to determine hourly SR on an incline surface using latitude, declination and clear index data. The results showed December and June indicated the highest and lowest SR. In 2013 at Sokoto, Sanusi, et al., reported on the application of artificial neural networks (ANNs) and regression methods based on Hargreaves-Samani and Angstrom Prescott technique to predict daily SR. The study used three years data on the mean daily sunshine hours, air temperature, relative humidity, day and month number as input variables to the ANN models. It indicated a strong predictive power with MBE, RMSE, MPE, and R^2 as 0.063, 0.164, -2.489%, and 0.965 for the training, and 0.103, 0.288, -4.177% and 0.959 for the testing respectively. In this study, estimation of global solar radiation (SR) at Abuja and northern Nigeria using temperature-based Hargreaves and Samani, Samani and Annandale models will be conducted to identify appropriate models for the areas within same geographical locations.

Model Descriptions

In order to assess the potential of solar energy arriving on the earth, empirical models are developed to predict the availability at locations within the same geographical regions. The Hargreaves-Samani, Samani and Annandale Models are presented. The techniques the determination of the daily extraterrestrial SR on horizontal surface (Iqbal, 1980) given by:

$$H_0 = \left\{\left(\frac{24}{\pi}\right) 3{,}600\right\} I_{SC}E_0 \sin\phi\sin\delta\ [(\pi/180)\omega_s - \tan\omega_s] \quad (1)$$

The pioneering work by Hargreaves-Samani expressed that R_s (global solar radiation) could be estimated from the square root of the difference - between daily maximum and daily minimum air temperature - and extraterrestrial radiation (H_o) (Hargreaves and Samani, 1985).

This model requires only two parameters, temperature and solar energy

$$R_S = R_aK_r\,(T_{max} - T_{min})^{0.5} \quad (2)$$

where T_{max} and T_{min} is the mean daily maximum and minimum air temperature (ºC), K_r is the empirical coefficient (0.16 for interior region and 0.19 for coastal region) (Hassan and Onimisi, 2013, Sanusi, et al, 2013).

$\sqrt{\Delta T} = (Tmax - Tmin)^{0.5} = (35.0 - 23.5)^{0.5} = 3.39$ºC

$R_S = R_aK_r\,(Tmax - Tmin)^{0.5} = 31.58 \times 0.16 \times 3.39 = 17.13$ MJ/m^2/day = H_i

On January 2, 2008 $\sqrt{\Delta T}$ = 3.46ºC and R_S = 17.47 MJ/m^2/day; measured value = 13.6 MJ/m^2/day.

Based on Hargreaves-Samani expression, Annandale's group in 2002, accounted for the effect of reduced atmospheric thickness on global SR. The correction factor K_r' is given by:

$$K_r^1 = (1 + 0.000027\,x\,M)K_r \quad (3)$$

$R_S = R_aK_r'(Tmax - Tmin)^{0.5} = (1 + 0.000027 \times M)\,K_rR_a\,(Tmax - Tmin)^{0.5}$

where M is the altitude of the site (Abuja = 342m); K_r is 0.16

$K_r' = (1 + 0.000027 \times 242)\ 0.16 = 0.1615$.

Samani for the first time in 2000, developed a quadratic relationship between K_r and the temperature difference built on Hargreaves-Samani model and is applied to locations between latitudes 7ºN and 50ºN on the earth (Abuja is 9.5^{0}N) according to Osuji (2010); and Adelabu (2011).

$$K_r' = 0.0018(Tmax - Tmin)^2 - 0.0433(Tmax - Tmin) - 0.4023 \quad (4)$$

The extraterrestrial SR (H_o) is expressed as

$$H_0 = \left\{\left(\frac{24}{\pi}\right) 3{,}600\right\} I_{SC}E_0 \sin\phi\sin\delta\ [(\pi/180)\omega_s - \tan\omega_s] \quad (5)$$

$$L^0 = \frac{2\pi(dn - 1)}{365} \quad (6)$$

$$E_0 = (r_0/r)^2 = 1 + 0.033\cos(360/365\,d_n) \quad (7)$$

$$\delta = 23.45\,\mathrm{Sin}\left\{\frac{360}{365}(d_n + 284)\right\} \quad (8)$$

$$\omega_s^0 = \cos^{-1}(-\tan\delta\tan\phi) \quad (9)$$

where L^0 is the day angle, E_o is the eccentricity correction factor of the earth's orbit; ω_s^0 is the sunrise hour angle; ϕ is the geographic latitudes in degrees (north positive) of the site under study (9.05º); δ is the Solar declination (Igbal, 1980).

Sunrise hour angle ω_{sr} is equal sunset hour angle ω_{ss} except for the sign difference. Morning (positive) afternoon upward (negative) and Solar Noon (Zero degree), it changes by 15º every hour. The day length N_d

can be computed for any day which is $2\omega_s$ when expressed in hours it is given by

$N_d = \frac{2}{15}\cos^{-1}(-\tan\delta\tan\phi)$

January 1-30, as shown in the table, substituting $E_{0,}$ Ws, ϕ, (Deg), L, δ, π, $E_0 = \frac{r_0}{r}$ = 1.0330 (dimensionless), I_{sc} = Solar constant (1367 Wm^{-2}), $w_s = \cos^{-1}(-\tan\delta\tan\phi)$ = 86.09^0 and δ = -23.19, = 9.05^0 (Latitude is 9.05^0) and π = 3.142 and for day 1:

$H_o = \left\{\left(\frac{24}{\pi}\right)3{,}600\right\}$ x 1367 x 1.0330 sin 9.05 sin (-23.19) $\left[\left(\frac{\pi}{180}\right)\right.$ x 86.09 – tan (86.09)] = 31.58 MJ/m^2/day.

Similarly for day 2 on January 2, H_o= 31.56 MJ/m^2/day till day 31 on January 31, H_o = 33.46 MJ/m^2/day. The parameters are represented in Table 1 for the daily values of the extraterrestrial SR and global SR at Abuja. From the mean daily maximum and minimum temperature (^{0}C), the values of $(\Delta T)^2$ and (ΔT) ^{0}C were used to calculate the daily values of the correction factor y K_r' proposed by the Samani Model, the values of K_r'.

Table 1: Solar Radiation Parameters (NIMET, 2012)

Days = d	L (deg)	E0	$W_{s\,(Deg)}$	δ= (Deg)	R (MJ/m2/day	2008 $\sqrt{\Delta T}$	2009 $\sqrt{\Delta T}$	2010 $\sqrt{\Delta T}$
1	0.00	1.0330	86.09	-23.19	31.58	3.39	4.15	4.24
2	0.98	1.0330	86.10	-23.11	31.56	3.46	3.87	4.25
3	1.97	1.0330	86.12	-23.03	31.64	3.75	3.83	4.05
4	2.96	1.0330	86.14	-22.93	31.69	3.96	3.73	4.30
5	3.95	1.0329	86.16	-22.83	31.74	3.49	3.81	4.23
6	4.93	1.0328	86.18	-22.72	31.78	2.83	3.87	4.09
7	5.92	1.0327	86.20	-22.61	31.81	2.72	3.51	4.25
8	6.90	1.0327	86.22	-22.49	31.84	3.31	3.00	4.00
9	7.89	1.0326	86.24	-22.36	31.85	3.19	3.08	4.06
10	8.88	1.0325	86.27	-22.36	31.94	3.59	3.15	4.00
11	9.86	1.0324	86.30	-22.08	32.03	3.85	3.29	3.66
12	10.85	1.0323	86.32	-21.93	32.01	3.62	3.10	4.29
13	11.84	1.0322	86.31	-21.98	32.98	3.35	3.49	4.04
14	12.84	1.0320	86.38	-21.62	32.15	3.96	3.37	3.81
15	13.81	1.0319	86.41	-21.45	32.20	3.70	3.56	3.74
16	14.79	1.0318	86.45	-21.27	32.34	3.82	3.48	4.15
17	15.78	1.0316	86.48	-21.09	32.37	3.90	3.25	3.67
18	16.77	1.0314	86.51	-20.90	32.39	4.14	2.98	3.63
19	17.75	1.0313	86.55	-20.71	32.51	3.94	3.07	4.00
20	18.74	1.0311	86.58	-20.51	32.52	3.70	2.81	4.04
21	19.73	1.0309	86.62	-20.30	32.61	2.92	3.02	4.24
22	20.71	1.0307	86.66	-20.09	32.70	3.59	3.56	4.12
23	21.70	1.0304	86.70	-19.87	32.78	3.81	3.74	4.34
24	22.68	1.0302	86.74	-19.65	32.86	3.70	4.94	4.11
25	23.67	1.0300	86.78	-19.42	32.93	3.97	2.82	3.87
26	24.66	1.0297	86.82	-19.18	32.97	3.51	3.48	3.92
27	25.64	1.0295	86.87	-18.94	32.14	3.74	3.26	3.70
28	26.63	1.0292	86.91	-18.70	33.18	3.81	3.07	3.33
29	27.62	1.0290	86.96	-18.44	33.32	3.87	2.92	3.61
30	28.60	1.0287	70.00	-18.19	33.35	3.59	2.94	4.29
31	29.59	1.0284	87.05	-17.92	33.46	3.94	3.96	4.06
Total	**458.6**	**31.9729**	**2664.12**	**-651.87**	**1003.23**	**112.12**	**106.11**	**124.09**

Table 2: Considering SR values for January 2008, 2009 and 2010 and Hargreaves-Samani model

Days (d)	Ra (MJ/m^2/day)	Rs 2008	Rs 2009	Rs 2010	Measured Value 2008	Measured Value 2009	Measured Value 2010
1	31.58	17.13	20.97	21.43	19.64	24.99	25.71
2	31.56	17.47	19.54	21.41	13.56	23.95	25.80
3	31.64	18.98	19.39	20.50	21.20	23.97	24.58
4	31.69	20.78	18.91	21.80	23.28	23.20	26.12
5	31.74	17.72	19.35	21.48	21.49	23.38	25.71
6	31.78	14.39	19.68	21.51	18.45	23.55	24.85
7	31.81	13.84	17.86	21.63	18.86	21.69	25.89
8	31.84	15.95	15.28	20.38	19.74	19.46	24.37
9	31.85	16.26	15.70	20.69	19.09	18.79	24.77
10	31.94	18.35	16.10	20.44	20.87	18.51	24.41
11	32.03	19.73	16.86	18.76	22.02	19.32	22.36
12	32.01	18.54	15.88	21.97	21.53	19.33	26.23
13	32.98	17.14	17.86	20.67	19.45	19.74	24.71
14	32.15	20.37	17.34	19.60	22.76	19.76	23.33
15	32.20	19.06	18.34	19.27	21.33	20.52	22.95
16	32.34	19.77	18.01	21.47	21.96	20.91	25.46
17	32.37	20.20	16.83	19.01	22.91	18.44	22.58
18	32.39	21.46	15.44	18.81	23.75	17.40	22.35
19	32.51	20.49	15.97	20.81	23.54	18.89	24.64
20	32.52	19.25	14.62	21.02	21.54	17.33	24.90
21	32.61	15.24	15.76	22.12	17.24	17.24	26.20
22	32.70	18.78	18.65	22.60	20.22	19.84	25.49
23	32.78	19.98	19.62	22.66	21.88	23.40	26.84
24	32.86	19.45	25.97	21.61	22.51	21.91	25.47
25	32.93	20.92	14.91	20.39	23.87	16.88	24.03
26	32.97	18.52	18.36	20.68	20.22	20.51	24.38
27	32.14	19.23	16.76	19.03	21.81	18.03	23.02
28	33.18	20.23	16.30	17.68	22.37	17.39	20.75
29	33.32	20.63	15.57	19.25	22.31	17.64	22.48
30	33.35	19.16	15.69	22.89	19.64	10.26	26.78
31	33.46	21.09	21.20	21.74	23.97	22.10	25.39
Total	**1003.23**	**580.11**	**548.72**	**643.31**	**653.01**	**618.32**	**762.53**
Mean	**32.36**	**36.87**	**34.72**	**40.81**	**21.10**	**19.50**	**24.50**

Table 3: Global SR at Abuja for January 2008, 2009 and 2010 and Annandale method (This study)

Days (d)	H_o MJ/m^2/day	2008 $\sqrt{\Delta T}$ (ºC)	2009 $\sqrt{\Delta T}$ (ºC)	2010 $\sqrt{\Delta T}$ (ºC)	Rs 2008 /MJ/m^2/day	Rs 2009 /MJ/m^2/day	Rs 2010 /MJ/m^2/day
1	31.58	3.39	4.15	4.24	21.17	17.29	21.62
2	31.56	3.46	3.87	4.25	19.73	17.64	21.66
3	31.64	3.75	3.83	4.05	19.59	19.16	20.69
4	31.69	3.96	3.73	4.30	19.09	20.27	20.01
5	31.74	3.49	3.81	4.23	19.53	17.89	21.68
6	31.78	2.83	3.87	4.09	18.96	14.52	20.99
7	31.81	2.72	3.51	4.25	18.03	13.97	21.83
8	31.84	3.31	3.00	4.00	15.43	16.09	20.57
9	31.85	3.19	3.08	4.06	15.84	16.41	20.88
10	31.94	3.59	3.15	4.00	16.25	18.52	20.63
11	32.03	3.85	3.29	3.66	17.02	19.92	18.93
12	32.01	3.62	3.10	4.29	16.03	18.71	22.18
13	32.98	3.35	3.49	4.04	18.03	17.30	20.87
14	32.15	3.96	3.37	3.81	17.50	20.56	19.78
15	32.20	3.70	3.56	3.74	18.51	19.24	19.45

16	32.34	3.82	3.48	4.15	18.18	19.95	21.68
17	32.37	3.90	3.25	3.67	16.99	20.39	19.19
18	32.39	4.14	2.98	3.63	15.59	16.43	18.99
19	32.51	3.94	3.07	4.00	16.12	25.94	21.00
20	32.52	3.70	2.81	4.04	14.76	19.43	21.22
21	32.61	2.92	3.02	4.24	15.90	15.38	22.33
22	32.70	3.59	3.56	4.12	18.80	18.96	21.76
23	32.78	3.81	3.74	4.34	19.80	20.17	22.98
24	32.86	3.70	4.94	4.11	26.22	19.64	21.81
25	32.93	3.97	2.82	3.87	15.05	21.11	20.58
26	32.97	3.51	3.48	3.92	18.53	18.69	20.87
27	32.14	3.74	3.26	3.70	17.45	20.02	19.80
28	33.18	3.81	3.07	3.33	16.45	20.42	17.84
29	33.32	3.87	2.92	3.61	15.71	20.83	19.43
30	33.35	3.59	2.94	4.29	15.83	19.34	23.11
31	33.46	3.94	3.96	4.06	21.40	21.29	21.94
Total	**1003.2**	**112.1**	**106.1**	**124.1**	**553.5**	**585.5**	**646.3**
Mean	**32.36**	**21.10**	**19.50**	**24.50**	**17.85**	**18.89**	**20.85**

Table 4: Global SR at Abuja for January 2008, 2009 and 2010 and Samani model

Days (d)	**R_a ($MJ/m^2/day$)**	**$\sqrt{\Delta T}$ ^0C 2008**	**$\sqrt{\Delta T}$ ^0C 2009**	**$\sqrt{\Delta T}$ ^0C 2009**	**R_s 2008 ($MJ/m^2/day$)**	**R_s 2009 ($MJ/m^2/day$)**	**R_s 2010 ($MJ/m^2/day$)**
1	31.58	3.39	4.15	4.24	15.96	26.84	29.77
2	31.56	3.46	3.87	4.25	16.28	20.65	30.13
3	31.64	3.75	3.83	4.05	18.94	20.07	24.32
4	31.69	3.96	3.73	4.30	22.40	18.66	79.16
5	31.74	3.49	3.81	4.23	16.54	19.77	29.55
6	31.78	2.83	3.87	4.09	15.68	20.80	25.37
7	31.81	2.72	3.51	4.25	15.72	16.70	30.36
8	31.84	3.31	3.00	4.00	15.51	15.52	23.32
9	31.85	3.19	3.08	4.06	15.55	15.49	24.78
10	31.94	3.59	3.15	4.00	17.38	15.58	23.39
11	32.03	3.85	3.29	3.66	20.54	16.01	18.09
12	32.01	3.62	3.10	4.29	17.67	15.60	31.86
13	32.98	3.35	3.49	4.04	15.99	17.18	22.84
14	32.15	3.96	3.37	3.81	22.73	16.17	20.03
15	32.20	3.70	3.56	3.74	18.62	17.29	19.17
16	32.34	3.82	3.48	4.15	20.32	16.79	27.49
17	32.37	3.90	3.25	3.67	21.65	15.92	18.41
18	32.39	4.14	2.98	3.63	30.64	15.78	17.99
19	32.51	3.94	3.07	4.00	20.94	15.85	23.81
20	32.52	3.70	2.81	4.04	18.81	16.06	22.52
21	32.61	2.92	3.02	4.24	16.00	15.90	30.74
22	32.70	3.59	3.56	4.12	17.80	17.30	26.96
23	32.78	3.81	3.74	4.34	20.42	19.45	34.44
24	32.86	3.70	4.94	4.11	19.00	24.33	26.86
25	32.93	3.97	2.82	3.87	23.52	16.24	21.55
26	32.97	3.51	3.48	3.92	17.31	17.12	22.53
27	32.14	3.74	3.26	3.70	19.67	16.35	19.17
28	33.18	3.81	3.07	3.33	20.67	16.18	16.53
29	33.32	3.87	2.92	3.61	21.81	16.35	18.30
30	33.35	3.59	2.94	4.29	18.15	18.79	33.19
31	33.46	3.94	3.96	4.06	25.26	23.65	26.03
Total	**1003.23**	**112.12**	**106.11**	**124.09**	**597.48**	**554.39**	**818.66**
Mean	**32.36**	**21.10**	**19.50**	**24.50**	**19.27**	**17.88**	**26.41**

RESULTS AND DISCUSSION

Based on the daily data for 10 years from 2001-2010 obtained from Abuja NIMET (table 1), the mean monthly global SR on horizontal surface were computed. The model analysis was done with the average daily maximum and minimum temperature from which, the mean monthly SR were determined. Considering SR values for January 2008, 2009 and 2010 and using Hargreaves-Samani model (Table 2), the global SR at Abuja for January 2008, 2009 and 2010 and Annandale method and Samani model (Table 3) respectively.

Comparison can be achieved using statistical tools to indicate the performance of each model for Abuja and its metropolis and areas within the same geographical region.

The MBE = $\frac{1}{N}\sum_{i=1}^{N}$ (Hi – yi) (MJ m^{-2} day^{-1})

It provides information on the long term performance of the models. A positive MBE gives the average amount of over estimation in the predicted values and a negative value gives an underestimation. A low MBE indicates good estimation.

Root Mean Square Error (RMSE) is given by:

RMSE = $\sqrt{\sum\ (\mathrm{yi}\ -\ \mathrm{yi})^2/\mathrm{N}}$ (MJ m^{-2} day^{-1})

The test on RMSE provides information on the short term performance of the models. It allows a term by term comparison of the actual deviation between the calculated and the measured values. It is always positive. RMSE expressed in percentage is used in comparing the models. It is always positive. The smaller the RMSE value the better the performance.

Percentage Root Mean Square Error:

% RMSE = $\frac{RMSE}{\overline{\mathrm{yi}}}$ x 100

Where: Hi = The Predicted value (estimated), yi is the measured values (Observed values),

N = Total number of observations. $\overline{H}$ = Mean of predicted (estimated) values, $\overline{\mathrm{yi}}$ = mean of measured values (observed values).

The MPE gives long term performance of the examined regression equations, a positive MPE values provides the averages amount of overestimation in the calculated values, while the negatives value gives underestimation. A low value of MPE is desirable (Abisoye and Abiodun, 2013).

The results indicated that Hargreaves-Samani and Annandale models were perfectly fitted continuously during summer and increases in winter. The validation of the models in terms of the MBE, RMSE and percentage RMSE were found to have low error values as expected in compliance with NIMET, 2012 (Table 5). When the day temperatures remain high and the heat is conserved so that the night temperature is also high, resulting in less temperature range during the day. The temperature difference takes into account changes in radiation due to proximity to oceans, mountains, and the altitude of the location. An observable trend has been revealed, a gradual rise in value of the extraterrestrial radiation which increases steadily with days of the month until it began to reach a pick where it will remains constant for some days and finally, it will takes a gradual deep downwards. The regions of continuous rise in extraterrestrial radiation can be attributed to the period of increased dryness of atmosphere from the effect of the departing cold weather characterized by haze, mist fog and dust which contributes to shade for the solar radiation to deliver its full strength on the surface (Chiemeka, 2008).

Once extraterrestrial radiation has reached its maximum, effect of the atmospheric scattering in the rainy season takes over. This is characterized by cool moist laden wind from the coast. Such wind contains aerosol that subsequently creates envelope that reduces the effect of further incidence of extraterrestrial radiation and so the downward trend results (Hassan and Onimisi, 2013).

A comparison of the values of the models used show that introducing an empirical constant as a function of temperature change, pressure, altitudes and latitudes give rise to variations in the results.

Hargreaves-Samani model is the best model for estimating global solar radiation at Abuja and for other interior regions within the same geographical region as it shows the best performances by taking first position in 2008 and 2010 from the MBE, RMSE and % RMBE values. The next alternative method is Annandale model also revealed better performances. Its corrected empirical coefficient used in Hargreaves-Samani as a function of elevation which accounts for the effect of reduced atmospheric thickness. The quadratic equation by Samani showed poor results and is not suitable when compared with the others and from the MBE, RMSE and %RMBE values. It is observed from the results that the percentage error between the measured and predicted values in general, is very low as expected (Yakubu and Medugu, 2012).

Total yearly SR in MJm/^{2}/day from 2001-2010 at Abuja was between 246.7 and 217.5 respectively (Table 6). Performance of the models as summarized in Table 7 indicated a good raking (1 and 2) for the models (Table 7) Total global SR at Abuja showed peak in 2001 and lowest in 2007. The diurnal variation of the average monthly SR at Abuja in showed minimum July 2008, 2009 and July, 2010 (Fig. 2) while 14th and 30th day of January 2010 was the lowest and highest respectively.

Its high irradiation values in the dry season associated with long duration of sunshine hours (above 6 hours/day) and less cloudy skies. The low irradiation values are in the rainy season (when the rain bearing clouds pervade the sky) associated with least sunshine hour (less than 5 hours/day).

CONCLUSION

Three temperature based models have been used to estimate Abuja global SR. Hargreaves-Samani and Annandale models were adequate because the observed data agrees with the experimental data. Due to improper maintenance culture or inability to get trained personnel to take daily records or delay in repairing damaged instruments, these models can be used with ease and reliability. The models will help in predicting the SR not only in this area but also places with similar geographical locations and in any parts of the guinea savannah. It revealed that the monthly average of global SR varies between 16.73 $MJm^{-2}day^{-1}$ in August and 25.02 $MJm^{-2}day^{-1}$in March throughout rainy and dry seasons. It has also indicated that during summer due to absorption, scattering, reflection and transmission by clouds, water vapour, carbon dioxide, and smog and other extraterrestrial particles and global SR decreases continuously and increases in winter in agreement with other research findings. The Government, Nigerian Energy Commission and Research Centers should encourage more studies in solar energy and potential evaluation in many parts of the country. The solution to energy crisis require proper action plan and implementation for a hassle free utilization of solar and other alternative energy resources.

Table 5: Mean Monthly Solar Radiation / MJm^2/day (NIMET 2012)

NIGERIAN METEOROLOGICAL AGENCY / NIMET

	Mean Monthly Solar Radiation / MJm^2/day									
Months	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
JAN.	23.5	23.5	22.3	22.3	22.5	20.4	19.0	21.1	19.5	24.5
FEB.	24.3	23.4	23.2	24.2	21.9	20.5	20.7	23.4	19.6	23.7
MAR.	23.6	22.1	22.7	23.4	22.0	21.1	23.4	21.8	20.1	22.6
APRIL	21.2	20.0	20.9	20.7	21.2	22.8	17.8	19.6	18.3	20.4
MAY	19.7	20.2	20.2	18.5	18.8	18.7	16.5	17.6	17.7	16.3
JUNE	18.6	18.5	16.7	18.0	17.5	17.8	15.5	17.3	15.8	15.0
JULY	16.7	17.4	17.1	17.6	16.4	16.9	14.6	15.3	15.1	14.5
AUG.	16.9	16.9	17.0	16.7	15.7	15.8	15.3	17.7	15.8	15.2
SEPT.	17.2	18.0	17.6	18.4	17.9	17.4	17.1	17.6	16.7	17.2
OCT.	19.6	18.2	18.5	18.6	18.4	18.0	18.4	20.0	17.8	18.1
NOV.	22.3	20.9	20.2	19.4	21.8	21.7	18.4	21.0	21.4	21.4
DEC.	23.1	22.8	22.5	22.3	21.4	23.5	20.8	21.0	21.5	21.5
Total	**246.7**	**241.9**	**238.9**	**240.1**	**235.5**	**234.6**	**217.5**	**233.4**	**219.3**	**230.4**

Table 6: Total Yearly Solar Radiation / $MJm/^2$/day 2001-2010 at Abuja

Year	**Global Solar Radiation**
2001	246.7
2002	241.9
2003	238.9
2004	240.1
2005	235.5
2006	234.6
2007	217.5
2008	233.4
2009	219.3
2010	230.4

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Table 7: Performance of the Models

Models	**Evaluation**			**Ranking**		
	MBE	**RMSE**	**% RMSE**	**2008**	**2009**	**2010**
Hargreaves-Samani	-2.39	2.73	12.94%	1	2	1
Annandale	-2.18	2.867	13.59%	2	1	2
Samani	-1.79	2.74	12.99%	3	3	3

1 = Best, 2 = Good and 3 = Not Suitable (poor)

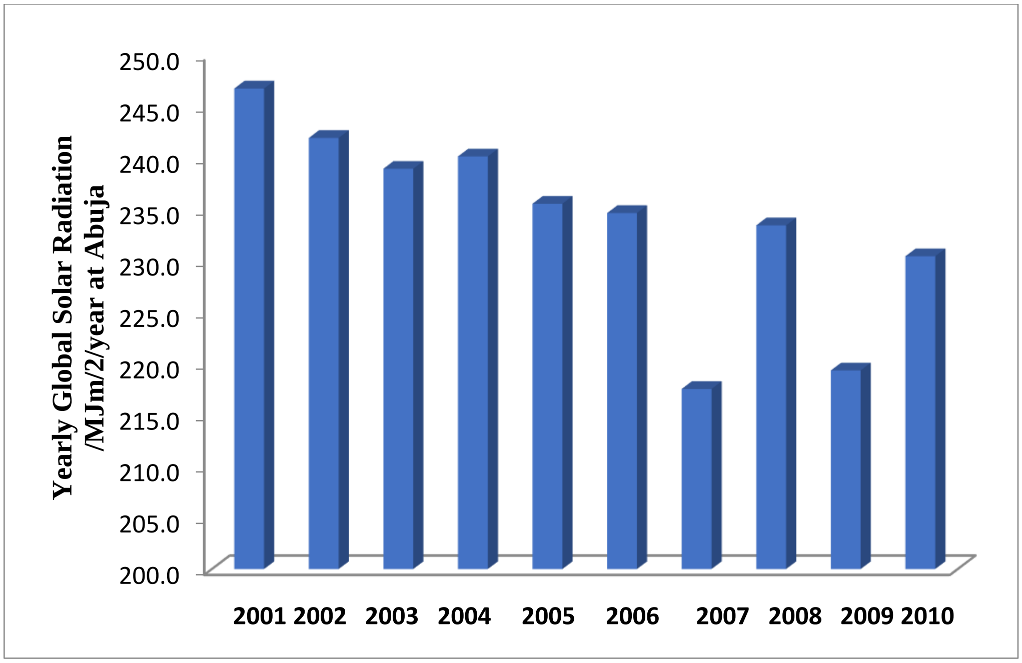
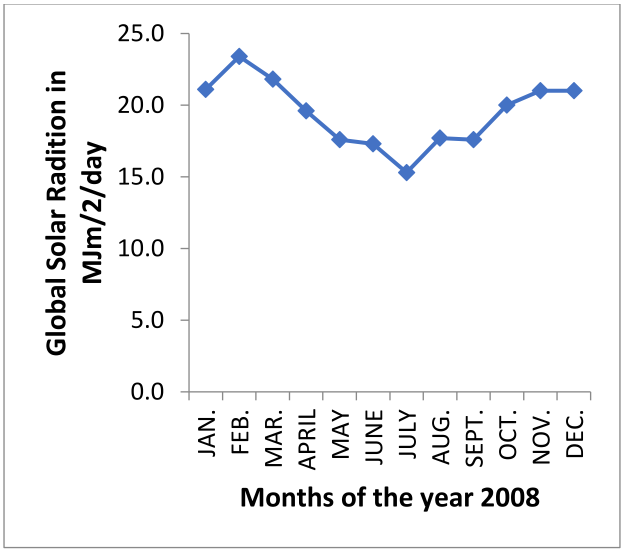
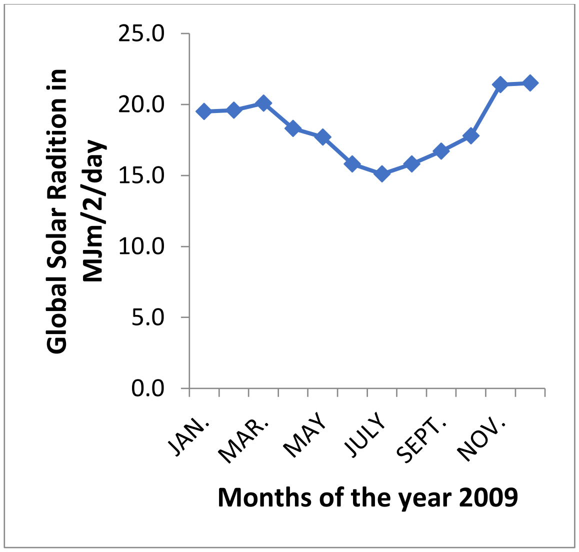


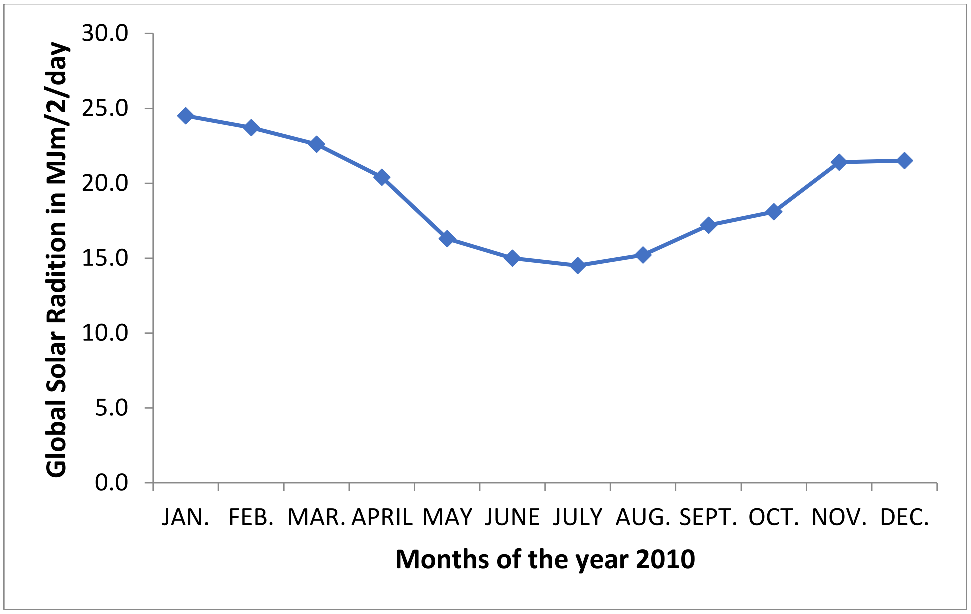
Figure 1: Total Global Solar Radiation at Abuja between 2001 and 2010 (NIMET, 2012)



(a)



(b)



(c)

Figure 2: Diurnal variation of the Average Monthly Solar Radiation at Abuja for (a) 2008 (b) 2009 (c) 2010 (NIMET, 2012)

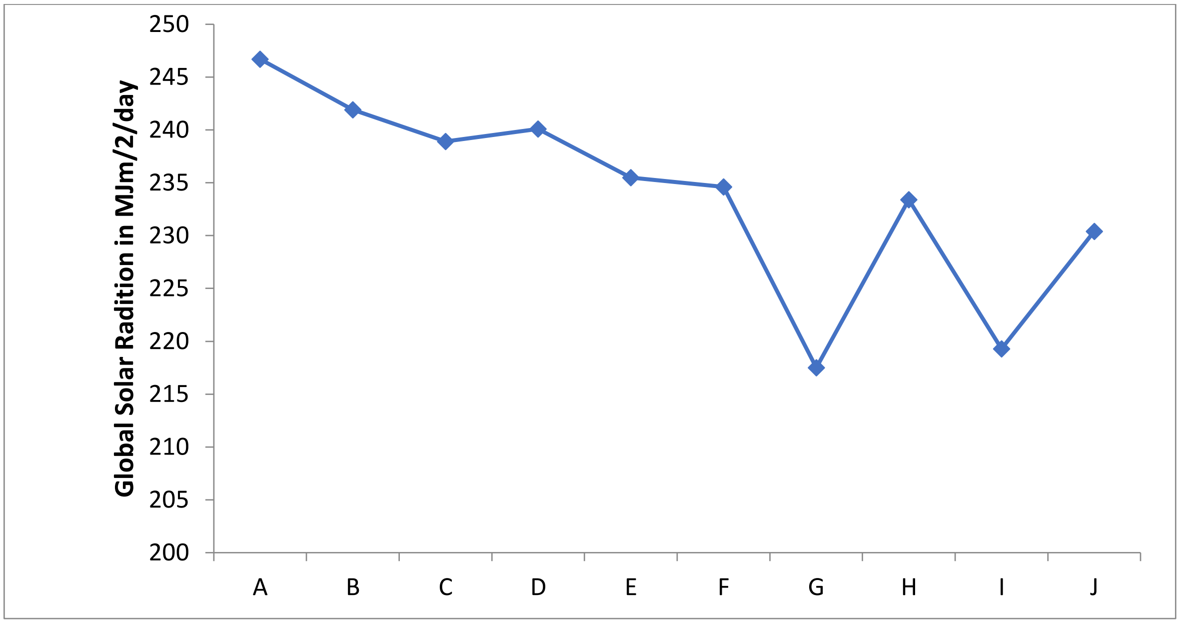


Figure 3: Yearly Values of Solar Radiation at Abuja between 2001 and 2010 (NIMET, 2012)

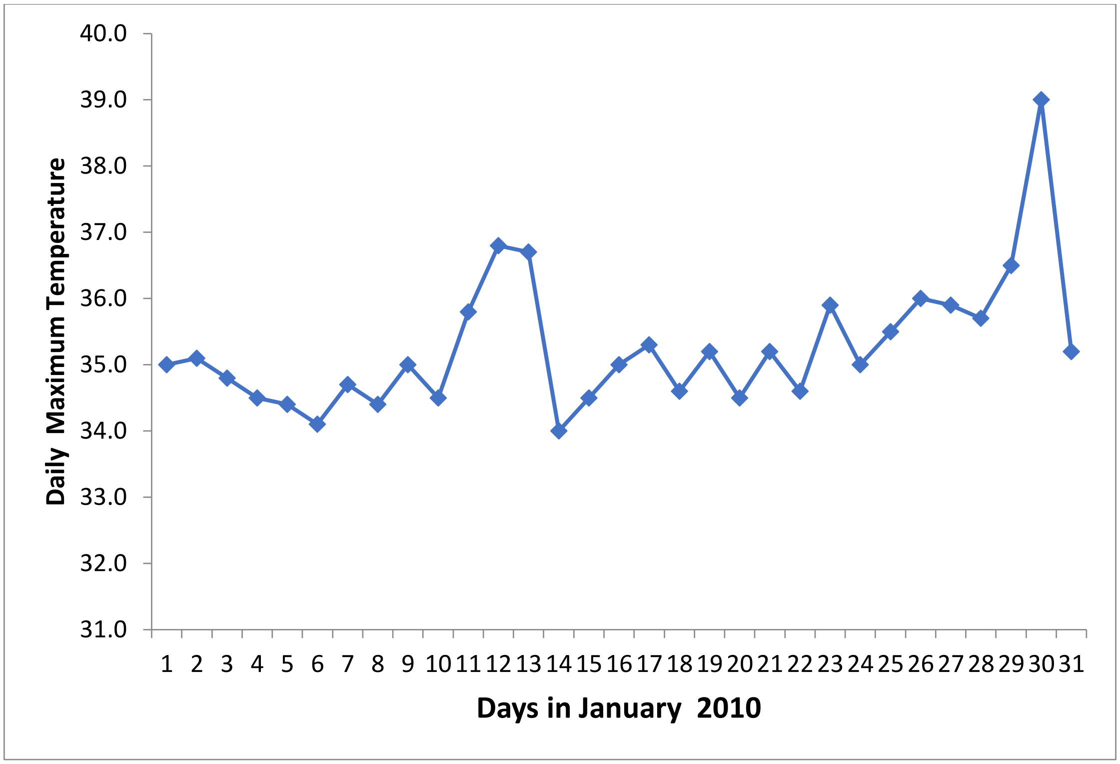


Figure 4: Daily Maximum Temperature for January 2010 (NIMET, 2012)

REFERENCES

Nwoke O. Okala, Uzoma C. Chigasa, Ibeto Cynthia, Okpara Chidimma, Nnaji Chibueze, Obi I. Onuoragbunam, Oparaku U. Ogbonna, (2011) Analysis and survey of The Application of Solar Dryers In Eastern Nigeria Int J Agric & Biol Eng Vol. 4 No.3 p 79

Chiemeka I. U (2008), Estimation of solar radiation at Uturu, Nigeria Intl Jnl of Physical Sciences V.3 (5), p 126-130

Hassan I. and M. Y. Onimisi (2013), Assessment of the Global Solar Energy Potential at Nigerian Defence Academy, Permanent Site Afaka Kaduna, Nigeria American Chemical Science Journal 3(3): 232-246

Ainah Priye Kenneth, Afa Tarilanyo John (2013) "Estimation of hourly solar radiation on an incline south facing surface in Port Harcourt city, Nigeria International Journal of Scientific & Engineering Research Volume 3, Issue 12, 1-4

Sanusi Y.K, Abisoye S.G and Abiodun, A.O (2013), Application of Artificial Neural Networks to Predict Daily Solar Radiation in Sokoto Intl Journal of Current Eng and Tech. 1-3

Yakubu D. and Medugu D. W., (2012), Relationship Between The Global Solar Radiation And The Sunshine Duration In Abuja, Nigeria, Ozean Journal of Applied Sciences 5(3), 1-5

Osueke C. O., P. Uzendu, I. D. Ogbonna (2013); Study and Evaluation of Solar Energy Variation in Nigeria, International Journal of Emerging Technology and Advanced Engineering Certified Journ, Volume 3, Issue 6, p 1-3

ICEED Nigeria (2006), Renewable Electricity Action Program, Federal Ministry of Power And Steel, Federal Republic of Nigeria, Garki II – Abuja, 1-5

Okoye A.C, Dioha I. J, Ezeonu F.C., Eboatu A.N. and Onuegbu T. U., (2011) Energy Crisis and Attendant Poverty and Environmental Problems: The Role Of Renewable Energy Nigeria Journal of Solar Energy, Vol. 22, 2011 pg.138-143

Ezekoye B. A., V. A. Ezekoye1, P. O. Ike, A C. Nwanya; (2011), Estimating Monthly Solar Radiation Of Nsukka Using Some Temperature Based Radiation Models Nigeria J of Solar Energy, Vol. 22, 2011 p 67-68

Osuji R.U, (2010) "Energy Systems and Designs" Lecture Materials, UNN, Nsukka, Nigeria (unpublished)

Malgwi, D. I and Ladan H. A, (2005) "Energy and Environmental Physics" Lecture Materials, University of Maiduguri, Nigeria (unpublished)

Adelabu, J.S.A, (2011) "Solar and Renewable Energy" Lecture Materials, Department of Physics, University of Abuja, Nigeria (unpublished)

Nigerian Meteorological Agency NIMET, (2012) Nig. Climate Review, Abuja 25-26

Hargreaves G.H, Samani Z. A., (1985) Reference Crop Evapo transpiration From Tem. Appl. Eng. Agric. 1, 96-99.

Igbal Muhammed (1983) An Introduction to solar radiation, Academic press New York, 1-84

Abdul-Malik Ismail, Idris Garba, Tijani B. N, (2009) Renewable Energy App. in Nig. Int'l J. of Eng. Sci. Vol 1(2) 1-10

Nwankwo S. N, Nnabuchi M. N and Ekpe J.E, (2012) Construction And Characterization of a Pyranometer Using Locally Available Materials For Global Solar Radiation Measurement Asian Transactions on Basic and Applied Sciences Vol. 02 Issue 04 Pp. 1-4

Ogunleye, I.O and Awogbemi, O. (2010), Constraints to the use of solar photovoltaic as a sustainable power source in Nigeria, American J. of Scientific and Industrial Research p.1-5.