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Assessment of the Global Solar Energy Potential at Auchi Area of Nigeria

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***Abstract*— This paper assessed the global solar radiation potential in Auchi area of Nigeria, for the period of January, February, March and April, 2014. Auchi lies between latitude $7^0$14' North and $7^0$34' North of the equator and longitude $6^0$14' East and $6^0$43' East of the Greenwich Meridian. The climate is subhumid and the average temperature is about 33^0C in the rainy season and about 42^0C in the dry season. Procedure employed involved the use of Hargreaves-Samani's equation as a method of estimating solar radiation using minimum climatological data. The method or model makes use of recorded daily maximum and manimum temperatures for the four months while weather station parameters (sunset hour angle, extraterrestrial solar radiation, etc) were directly derived from the latitude of the area. The model provides a simple and low cost system for estimating solar radiations because it does not require expensive hardware for data processing nor information from neighbouring meteorological stations for spatial interpolation. The global solar radiation at Auchi area of Nigeria within the period of study exhibits monthly variation but an average or mean of 22.61MJ/m^2/day was obtained for the four months. The information from the study conducted will go a long way to establish solar irradiation data on the area which will then form a baseline for any planned application of solar irradiation in the area, such as in the design of solar photovoltaic systems.**

***Index Terms*—Global solar radiation, Climatological data,**

I. INTRODUCTION

The study of renewable and sustainable energy resources, such as solar energy are encouraged today because energy resources based on fossil fuels are rapidly decreasing and causes environmental pollution. The knowledge of the dwindling level of these resources (fossil fuels) and their related environmental challenges is generating the necessity to shift emphasis from the use of fossil fuels to renewable energy resources such as solar radiation (Hassan and Onimisi, 2013). The trends of energy indicate that world oil production will reach peak and start a long downward slide when the fossil fuels and gas would have been consumed (Augustine and Nnabuchi, 2009). Solar radiation is the largest renewable energy source and more attention has be paid to it for the past few decades because of its importance (Ugwu and Ugwuanyi, 2011).

Solar radiation is the radiant energy that is emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy (Hinrichs, 1996). It is the main driving force of the processes in the atmosphere, as well as in the biosphere. This implies that measured daily global solar radiation is an important factor in most cropping systems and water balance models. Knowledge of solar radiation data is also indispensable for many solar-energy-related applications. Comprehensive knowledge of global solar radiation of a particular location is a useful tool in the study and design of the economic viability of devices that depends on the use of solar energy. The knowledge of the amount of solar radiation in a given location or area is essential in the field of solar energy physics and in the design and installation of solar photovoltaic systems (Nando, 2012). This in effect helps one to have a fair knowledge of the insulation power potential over the location or area. For the fact that there is the campaign for the popularization of solar energy for domestic and industrial uses, the need to know how to evaluate insulation levels for any area becomes paramount. When that is done, the introduction, development and sustainability of solar energy technology will be assured (Chineke, 2002).

In this work, the Hargreaves – Samani equations were used to assess the global solar radiation at Auchi Area of Nigeria based on the available climatological parameters of measured maximum and minimum temperatures. The study makes use of a statistical model that adopts the available data to assess the global solar radiation at Auchi Area of Nigeria for the months of January, February, March and April, 2014. The main aim of this work is to assess the global solar radiation of Auchi Area of Nigeria. These data will enable the designers of solar photovoltaic systems to know if a solar photovoltaic system will function properly in Auchi Area of Nigeria and also in selecting the number of solar panels and number of batteries for a solar photovoltaic system in Auchi Area of Nigeria. According to Offiong (2003), the average solar radiation received in Nigeria per day is as high as 20MJ/m^2/day (55.6kwh/m^2/day) depending on the time of the year and location. It should be noted that "insulation" is the summation of the amount of solar energy arriving at a unit area (m^2) during one hour while "insolation" is the average daily global solar radiation i.e. global solar insolation (radiation) is the average solar energy arriving at a unit area (m^2) during one day (US Technology White Paper, 2006).

II. THE RESEARCH AREA

Auchi where the sun's radiation data were collected lies between latitude $7^0$14' North and $7^0$34' North of the equator and longitude $6^0$14' East and $6^0$43' East of the Greenwich Meridian. For its relative location, Auchi is bounded by Jattu to the East, Aviele to the South, Warrake to the West and Iyuku to the North. She is located on a slightly undulating tarrain with elevation of about 300m above sea level. There are some spot heights intruding on the slightly low areas where the bulk of the populace is settled (Olatunde, 2013). Auchi has a tropical climate characterized by two distinct seasons, the wet and dry seasons. The wet seasons occurs between April and October with a peak in August while the

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dry season last from November to April with a cold harmattan spell between December and January. The climate is sub-humid and the average temperature is about 33^0C in the rainy season and about 42^0C in the dry season (Oguntoyinbo, 2009).

III. MATERIALS AND METHOD

Hargreaves method of estimating global solar radiation from maximum and minimum daily temperatures was employed for the purpose of this research work. The temperature data were recorded for a period of four months in Auchi area of Nigeria. A mercury Thermometer was placed on top of an array of solar panels and the temperature readings taken from 6.00AM in the morning to 8.00PM in the evening, everyday for the four months (January to April, 2014). The maximum and minimum daily temperatures were obtained from these readings and used in the Heagreaves – Samani's equations.

Heagreaves and Samani (1982) were among the first researchers to suggest that global solar radiation could be estimated from the difference between daily maximum and minimum air temperatures and extraterrestrial solar radiation. The form of the equation introduced by Hargreaves and Samani is:

$$R_s = K_r \left(T_{\max} - T_{\min}\right)^{0.5} R_a \quad \text{-- -- -- -- -- --} \ (1)$$

Where T_{Max} and $T_{\min}$ are mean daily maximum and minimum air temperatures (^{0}C), R_a is the extraterrestrial solar radiation and K_r is the empirical coefficient. Initially, K_r was set to 0.17 for arid and semi arid climates. Hargreaves (1994) later recommended using $K_r = 0.16$ for interior regime and $K_r = 0.19$ for coastal regime. Auchi, being located in an interior position, K_r was taken to be 0.16. The extraterrestrial radiation, R_a in MJ/m^2/day can be calculated for any given day of the year and latitude according to equations from Duffie and Beckman (2006).

$$R_a = \frac{1440}{\pi}\left[G_{sc} d_r\right]\left[\Psi_s Sin(\theta) Sin(\delta) + Cos(\theta) Cos(\delta) Sin(\Psi_s)\right] \quad \text{-- --} \ (2)$$

Where G_{SC} = solar constant (0.0820MJ/m^2/minute)

d_r = Inverse relative distance from the earth to the sun, Ψ_s = sunset hour angle (rad),

σ = Latitude (rad) and δ = solar declination (rad).

In the equation 2,

$$d_r = 1 + 0.033 Cos\left[\frac{2\pi JD}{365}\right] \quad \text{-- -- -- -- -- --} \ (3)$$

$$\delta = 0.409 Sin\left[\frac{2\pi JD}{365} - 1.39\right] \quad \text{-- - -- -- --} \ (4)$$

$$\Psi_s = arCos\left(-\tan\theta \tan\delta\right)$$

Where JD = day of the year.

From the daily maximum and minimum temperatures readings, the temperature difference (TD) and the average temperatures were calculated for each day as shown in Table 1.1.Table 1.2 is a summary of the temperature values for the months of January to April, 2014 while Table 1.3 shows how d_r, δ, ψ_s, R_a and R_s were calculated for 1st of January, 2014.

Table 1.1: Maximum and Minimum Temperature Readings for the Months of January to April, 2014.

DATE	JANUARY				FEBRUARY				MARCH				APRIL			
	T_{max} ^oC	T_{min} ^oC	T.D	T.a	T_{max} ^oC	T_{min} ^oC	T.D	T.a	T_{max} ^oC	T_{min} ^oC	T.D	T.a	T_{max} ^oC	T_{min} ^oC	T.D	T.a
1	46	27	19	36.5	43	26	17	34. 5	43	26	17	33	44	30	14	37
2	46. 5	29	17.5	37.8	42.5	25.5	17	34	48	27	21	37.5	42	31	11	36.5
3	45	28	17	36.5	42	25	17	33.5	47	28	19	37.5	37	27	10	32
4	47	26	21	36.5	44	25	19	34.5	48	28	20	38	41	29	12	35
5	43	27	16	35	45	25	20	35	47	27	20	37	46	31	15	3825
6	42	26	16	34	46	28	18	37	43	28	15	34.5	43	26	17	34.5
7	41	25	16	33	46	30	16	38	46	27	19	36.5	44	31	13	37.5
8	42	26	16	34	43	28	15	35.5	47	30	17	38.5	42	29	13	35.5
9	42. 5	26	16.5	34.5	47	30	17	38.5	45	28	17	36.5	41	31	10	36
10	44	27	17	35.5	45	29	16	37	46	29	17	37.5	40	26	14	33
11	43	28.5	14.5	35.8	48	28	20	38	48	28	20	38	42	30	12	36
12	42	26	16	34.3	8.5	28	10.5	33.3	45	27	18	36	40	26	14	33
13	43	26	17	34.5	43.5	26	17.5	34.8	46	29	17	37.5	38	25	13	31.5
14	46	29	17	37.5	43.5	28	15.5	35.8	45	28	17	36.5	42	26	16	34
15	46	28	18	37	43	25	18	34	46	28	18	37	40	26	14	33
16	47	27	20	37	47	30	17	38.5	47	29	18	38	42	26	16	34
17	43	23	20	33	44	26	18	35	48	30	18	39	44	23	18	35
18	42	29. 5	12.5	35.8	43	29	14	36	41	28	13	34.5	36	23	13	29.5
19	44	28	16	36	44	25	19	34.5	48	30	18	39	40	25	17	31.5
20	43	29	14	36	43	26	17	34.5	46	28	18	37	36	26	11	28
21	46	28. 5	17.5	37.5	46	28	18	37	45	27	18	36	41	26	15	33.5
22	45	33	12	34	45	30	15	37.5	46	27	19	36.5	39	26	13	32.5
23	44	26	18	5	45	27	18	36	46	28	18	37	45	26	19	35.5
24	42	29. 5	12.5	35.8	46	30	16	38	45	25	20	35	39	28	11	33.5
25	42	24. 5	15.5	33.3	45	28.5	16.5	36.8	44	28	16	36	35	27	8	31
26	45	27	18	36	44	24	20	34	43	27	16	35	33	23	10	28
27	48	33	15	40.5	46	30	16	38	37	27	20	32	43	24	19	33
28	48	30	18	39	46	26	20	36	48	28	20	38	37	24	13	30.5
29	42	26	16	3433	-	-	-	-	46	27	19	36.5	35	25	10	30
30	39	27	12	34.5	-	-	-	-	46	26	20	36	39	28	11	33.5
31	41	28	13	34.5	-	-	-	-	47	22	25	34.5	-	-	-	-
MEAN	43. 9	27. 5	16. 2	35. 9	44. 4	27. 4	17. 1	37.1	45.6	27.6	18.3	36.5	40.2	26.8	13.4	32.4
MAX	48	33	21	40.5	48	30	20	38.5	48	30	21	39	46	31	19	38.5
MIN.	39	23	12	33	42	24	10.5	33.3	41	22	13	32	33	23	10	28

Table 1.2: Summary of the Temperature Values For the Months of January to April, 2014.

	January 2014				February 2014				March 2014				April 2014			
	T_{ma} (^0C)	T_{mn} (^0C)	TD	Ta	T_{ma} (^0C)	T_{mn} (^0C)	TD	Ta	T_{ma} (^0C)	T_{mn}	TD	Ta	T_{ma} (^0C)	T_{mn} (^0C)	TD	Ta
MEAN	43.9	27.5	16.3	35.9	44.4	27.4	17.1	37.1	45.6	27.6	18.5	36.5	40.2	26.8	13.4	32.4
MAX	48	33	21	40.5	48	30	20	38.5	48	30	21	39	46	31	19	38.5
MIN	39	23	12	33	42	24	10.5	33.3	41	22	13	32	33	23	10	28

Note: T_{max} Maximum Temperature
T_{min} Minimum Temperature
TD Temperature Difference
Ta Average Temperature

Table 1.3: Calculation of d_r, δ, ψ_s, R_a and R_s for 1st of January, 2014

(1) Inverse relative distance from the earth to the sun,

$$d_r = 1 + 0.33 Cos \frac{2\pi JD}{365} \quad \text{Eqn. 3}$$

Where JD = day of the year = 01

$$\therefore d_r = 1 + 0.33 Cos\left[\frac{2\pi \times 01}{365}\right] = 1 + 0.33 Cos(0.0172) = 1.32995 rad.$$

(2) Solar declination, $\delta = 0.409 Sin\left[\frac{2\pi JD}{365} - 1.39\right]$ -- -- eqn. 4

$$= 0.409 Sin(-1.372785794) = -0.401008092 \text{ rad.}$$

(3) Sunset hour angle, $\Psi_s = arCos[-\tan\vartheta \tan\delta]$ -- -- eqn. 5

$$= arCos[-tan(0.122)\ tan(-0.401008092)]$$
$$= arcos[-0.123(-0.423)] = arCos(0.05215)$$
$$= 1.518622 \text{ rad.}$$

(4) Extraterrestrial solar radiation,

$$R_a = \frac{1440}{\pi}[G_{SC}.dr][\Psi_S Sin(\Sigma)Sin(\delta) + Cos(\Sigma)Cos(\delta)Sin(\Psi_S)] \quad \text{eqn. 2}$$

$$= \frac{1440}{\pi}[0.0820 \times 1.32995][1.518622 Sin(0.122)Sin(-0.401008092)]$$
$$+Cos(0.122)Cos(-0.401008092)Sin(1.518622)]$$
$$= 458.37[0.10906][-0.0713 + 0.9117]$$
$$= 49.9898 \times 0.8404 = 41.98 MJ/m^2/day$$
$$\frac{41.98 MJ/m^2/day \times 1000kw}{60m \times 60s} = 11.66 kwh/m^2/day$$

(5) Global Solar Radiation $R_S = K_r[T_{max} - T_{min}]R_a$ -- eqn. 1

$$= 0.16[19]^{0.4} \times 41.98 MJ/m^2/day$$
$$= 0.16 \times 3.25 \times 41.98 = 21.83 MJ/m^2/day \text{ or}$$
$$\frac{21.83 MJ/m^2/day \times 1000}{60m \times 60s} = 6.06 kwh/m^2/day$$

The procedure shown in Table 1.3 was repeated for all the other days from 2nd of January, 2014 to the 30th of April, 2014 and the results shown in Tables 1.4 and 1.5 while Table 1.6 is a summary of the radiation values.

Table 1.4: Calculated Values of the Inverse Relative Distance from the Earth to the Sun (dr), Solar Declinations (δ), and the Sun Set Hour Angles (ψ_s) for the Months of January to April, 2014.

	JANUARY				FEBRUARY				MARCH				APRIL			
DATE	D Year	dr	δ	ψ_s	D Year	dr	δ	ψ_s	D Year	dr	δ	ψ_s	D Year	dr	δ	ψ_s
1	1	1.3299	-0.4010	1.51862	32	1.2811	-0.3043	1.5322	60	1.1691	-0.1429	1.5531	91	1.0014	0.0718	1.5796
2	2	1.3296	-0.3996	1.5190	33	1.2782	-0.2996	1.5328	61	1.1642	-0.1364	1.554	92	0.9957	0.0787	1.5805
3	3	1.3290	-0.3967	1.5193	34	1.2751	-0.2947	1.5334	62	1.1592	-0.1297	1.5548	93	0.9901	0.0856	1.5813
4	4	1.3284	-0.3948	1.5195	35	1.2722	0.2898	1.5341	63	1.1542	-0.1230	1.5556	94	0.9844	0.0925	1.5822
5	5	1.3279	-0.3925	1.5197	36	1.2686	-0.2848	1.5362	64	1.1492	-0.1162	1.5564	95	0.9787	0.0993	1.5831
6	6	1.3271	0.3902	1.5198	37	1.2653	-0.2797	1.5355	65	1.1441	-0.1095	1.5573	96	0.9730	0.1062	1.5839
7	7	1.3263	-0.3889	1.5199	38	1.2618	-0.2746	1.5361	66	1.1389	-0.1027	1.5581	97	0.9674	0.1129	1.5847
8	8	1.3253	-0.3863	1.5200	39	1.2583	-0.2692	1.5369	67	1.1338	-0.0959	1.5589	98	0.9617	0.1197	1.5856
9	9	1.5241	-0.3841	1.5202	40	1.2548	-0.2639	1.5376	68	1.1286	-0.0890	1.5598	99	0.9561	0.1264	1.5864
10	10	1.3235	-0.3822	1.5204	41	1.2512	-0.2585	1.5383	69	1.1233	-0.08213	1.5607	100	0.9504	0.1331	1.5873
11	11	1.3223	-0.3800	1.5206	42	1.2474	-0.2530	1.5389	70	1.1180	-0.07524	1.5615	101	0.9449	0.1397	1.5880
12	12	1.3211	-0.3781	1.5209	43	1.2437	-0.2475	1.5397	71	1.1127	-0.0688	1.5624	102	0.9393	0.146	1.5889
13	13	1.3218	-0.3756	1.5211	44	1.2397	-0.2418	1.5404	72	1.1074	-0.0614	1.5632	103	0.9337	0.1529	1.5899
14	14	1.3200	-0.3732	1.5215	45	1.2358	-0.2361	1.5412	73	1.1019	-0.0544	1.5641	104	0.9282	0.1594	1.5906
15	15	1.3191	-0.3702	1.519	46	1.2318	-0.2303	1.5419	74	1.0966	-0.0474	1.5649	105	0.9226	0.1658	1.5914
16	16	1.3176	-0.3672	1.5223	47	1.2278	-0.2243	1.5427	75	1.0911	-0.04089	1.5659	106	0.9171	0.1722	1.5922
17	17	1.3160	-0.3640	1.5239	48	1.2236	-0.2185	1.5435	76	1.0856	-0.0333	1.5667	107	0.9116	0.1786	1.5930
18	18	1.3143	-0.3610	1.5243	49	1.2194	-0.2126	1.5442	77	1.0801	-0.0264	1.5676	108	0.9062	0.1849	1.5938
19	19	1.3225	-0.3554	1.5249	50	1.2151	-0.2065	1.5450	78	1.0746	-0.01934	1.5684	109	0.9007	0.1912	1.5946
20	20	1.3106	-0.3539	1.5253	51	1.2108	-0.2004	1.5458	79	1.0691	-0.0123	1.5693	110	0.8953	0.1974	1.5954
21	21	1.3086	-0.3503	1.5258	52	1.2063	-0.1942	1.5460	80	1.0635	-0.0053	1.5701	111	0.8899	0.2035	1.5962
22	22	1.3066	-0.3466	1.5264	53	1.2019	-0.1880	1.5474	81	1.0579	0.0018	1.5710	112	0.8846	0.2096	1.5969
23	23	1.3044	-0.3428	1.5269	54	1.1974	-0.1817	1.5481	82	1.0523	0.0088	1.5728	113	0.8793	0.2156	1.5978
24	24	1.3022	-0.3389	1.5274	55	1.1928	-0.1754	1.5489	83	1.0467	0.0158	1.5728	114	0.8740	0.2215	1.5985
25	25	1.2999	-0.3350	1.5280	56	1.1882	-0.1690	1.5498	84	1.041	0.0229	1.5736	115	0.8688	0.2274	1.5993
26	26	1.2975	-0.3309	1.5285	57	1.1835	-0.1626	1.5506	85	1.0354	0.0299	1.5736	116	0.8636	0.2332	1.6000
27	27	1.2950	-0.3267	1.5291	58	1.1787	-0.1577	1.5512	86	1.0300	0.369	1.5753	117	0.8585	0.2389	1.6001
28	28	1.2924	-0.3224	1.5297	59	1.1739	-0.1496	1.5522	87	1.0241	0.0439	1.5762	118	0.8534	0.2447	1.6015
29	29	1.2897	-0.3180	1.5303	-	-	-	-	88	1.0185	0.0509	1.5771	119	0.8483	0.2503	1.6022
30	30	1.2809	-0.3136	1.5309	-	-	-	-	89	1.0128	0.057	1.5779	120	0.8432	0.2558	1.6029
31	31	1.2844	-0.3089	1.5315	-	-	-	-	90	1.0071	0.0649	1.5788	-	-	-	-

Note: dr, δ and ψ_s are in radians.

Table 1.5: Calculated Values of the Extraterrestrial Solar Radiation (R_a) and the Global Solar Radiation (R_s) or Insolation for the Months of January to April, 2014. Error = ±0.07 ±0.04

	JANUARY				FEBRUARY				MARCH				APRIL			
DAY	D Year	T.D	R_a MJm^{-2} Per/day	R_s MJm^{-2} Per/day	D Year	T.D	R_a MJm^{-2}Per/day	R_s MJm^{-2} Per/day	D Year	T.D	R_a MJm^{-2} Per/day	R_s MJm^{2} Per/day	D Year	T.D	R_a MJm^{-2} Per/day	R_s MJm^{2} Per/day
1	1	19	41.92	21.83	32	17	44.55	22.14	60	17	47.79	23.75	91	14	50.19	23.08
2	2	17.5	41.96	21.1	33	17	44.66	22.19	61	21	47.8	25.9	92	11	50.24	20.98
3	3	17	41.98	20.863	34	17	44.77	22.25	62	19	48	21.94	93	10	50.27	20.2
4	4	21	42.12	22.779	35	19	44.89	23.31	63	20	48.1	25.52	94	12	50.31	21.75
5	5	16	42.14	20.44	36	20	45	23.86	64	20	48.21	25.57	95	15	50.34	23.79
6	6	16	42.16	20.44	37	18	45.12	21.88	65	15	48.31	23.43	96	17	50.37	25.06
7	7	16	42.19	20.44	38	16	45.23	21.94	66	19	48.41	25.15	97	13	50.4	22.5
8	8	16	42.22	20.44	39	15	45.35	22	67	17	48.47	24.09	98	13	50.42	22.51
9	9	16.5	42.34	20.69	40	17	45.47	22.05	68	17	48.6	24.15	99	10	50.45	20.28
10	10	17	42.48	21.11	41	16	45.59	22.11	69	17	28.7	24.2	100	14	50.47	23.21
11	11	14.5	42.5	19.86	42	20	45.7	24.24	70	20	48.79	25.87	101	12	50.49	21.83
12	12	16	42.6	20.7	43	10.5	45.84	20.14	71	18	48.88	24.85	102	14	50.5	23.22
13	13	17	42.7	21.22	44	17.5	45.94	23.1	72	17	48.96	24.33	103	13	50.52	22.55
14	14	17	42.72	21.22	45	15.5	46.06	22.06	73	17	49.04	23.49	104	16	50.53	24.51
15	15	18	42.86	21.79	46	18	46.13	23.48	74	18	49.13	24.98	105	14	50.54	23.24
16	16	20	42.94	22.77	47	17	46.3	23	75	18	49.22	25.02	106	16	50.54	23.89
17	17	20	43.04	18.82	48	18	46.42	23.6	76	18	49.3	25.07	107	18	50.55	22.56
18	18	12.5	43.1	20.94	49	14	46.53	21.39	77	13	49.37	22.04	108	13	50.55	22.1
19	19	16	43.19	19.95	50	19	46.65	24.24	78	18	49.45	25.14	109	17	50.55	23.24
20	20	14	43.32	21.92	51	17	46.77	23.24	79	18	49.64	25.24	110	11	50.56	21.11
21	21	17.5	43.41	18.82	52	18	46.89	23.84	80	18	49.59	25.21	111	15	50.55	21.85
22	22	12	43.5	22.81	53	15	47	22.22	81	19	49.65	25.8	112	13	50.55	22.56
23	23	18	43.6	19.17	54	18	47.12	23.96	82	18	49.72	25.27	113	19	50.54	25.08
24	24	12.5	43.7	20.2	55	16	47.23	22.91	83	20	49.78	26.4	114	11	50.53	21.1
25	25	15.5	43.8	22.98	56	16.5	47.34	23.25	84	16	49.84	24.17	115	8	50.52	18.57
26	26	18	43.9	20.32	57	20	47.46	24.13	85	16	49.9	24.2	116	10	50.51	20.3
27	27	15	44.01	22.8	58	16	47.54	23.06	86	20	49.96	26.49	117	19	50.5	23.87
28	28	18	44.11	22.45	59	20	47.68	25.29	87	20	50	26.52	118	13	50.49	22.54
29	29	16	44.22	21.45	-	-	-	-	88	19	50.06	26	119	10	50.47	20.28
30	30	12	44.33	19.16	-	-	-	-	89	20	50.11	26.57	120	11	50.45	21.06
31	31	13	44.43	19.83	-	-	-	-	90	25	50.26	26.65	-	-	-	-
MEAN	16	16.3	43.02	20.21	45.5	17.1	46.01	22.89	75	18.3	79.13	25.03	106.5	13.4	49.8	22.29
MAX	31	21	44.43	22.82	59	20	47.89	25.29	90	25	50.26	26.65	120	19	50.56	25.08
MIN	1	12	41.92	18.81	32	10.5	44.55	20.14	60	13	47.79	22.04	91	8	50.19	18.57

Table 1.6: Summary of Radiation Values for the Months of January to April 2014.

	JANUARY 2014		FEBRUARY 2014		MARCH 2014		APRIL 2014	
	Extraterrestrial Solar Radiation (R_a)	**Global Solar Radiation (R_s)**	**Extraterrestrial Solar Radiation (R_a)**	**Global Solar Radiation (R_s)**	**Extraterrestrial Solar Radiation (R_a)**	**Global Solar Radiation (R_s)**	**Extraterrestrial Solar Radiation (R_a)**	**Global Solar Radiation (R_s)**
Mean	43.02(MJ/m^2/day) Or 11.95 KWh/m^2/day)	20.21 (MJ/m^2/day) Or 5.61(KWh/m^2/day)	46.01(MJ/m^2/day) Or 12.78(KWh/m^2/day)	22.89(MJ/m^2/day) Or 6.36(KWh/m^2/day)	49.13(MJ/m^2/day) Or 13.65(KWh/m^2/day)	25.03(MJ/m^2/day) Or 6.95(KWh/m^2/day)	49.80(MJ/m^2/day) Or 13.83(KWh/m^2/day)	22.29(MJ/m^2/day) Or 6.19(KWh/m^2/day)
Maximum	44.43(MJ/m^2/day) Or 12.34(KWh/m^2/day)	22.82(MJ/m^2/day) Or 6.34(KWh/m^2/day)	47.89(MJ/m^2/day) Or 13.30(KWh/m^2/day)	25.29MJ/m^2/day) Or 7.025(KWh/m^2/day)	50.26(MJ/m^2/day) or 13.96(KWh/m^2/day)	26.65(MJ/m^2/day) Or 7.40(KWh/m^2/day)	50.56(MJ/m^2/day) Or 14.04(KWh/m^2/day)	25.08(MJ/m^2/day) Or 5.16(KWh/m^2/day)
MINIMUM	41.92(MJ/m^2/day) Or 11.64(KWh/m^2/day)	18.81(MJ/m^2/day) Or 5.23(KWh/m^2/day)	44.55(MJ/m^2/day) Or 12.38(KWh/m^2/day)	20.14(MJ/m^2/day) Or 5.59(KWh/m^2/day)	47.79(MJ/m^2/day) Or 13.28(KWh/m^2/day)	22.04(MJ/m^2/day) Or 6.12(KWh/m^2/day)	50.19(MJ/m^2/day) Or 6.12(KWh/m^2/day)	18.57(MJ/m^2/day) Or 5.16(KWh/m^2/day)

Note: The mean or average Global Solar radiation for the Four Months is 22.61(MJ/m^2/day or 6.28kwh/m^2/day.

4.3.2 Graphs of maximum and minimum temperatures against each day were plotted as shown in Fig. 1.1 for January, Fig. 1.2 for February, Fig. 1.3 for March and Fig. 1.4 for April, 2014. The values of the daily extraterrestrial solar radiation calculated for the months of January, February, March and April, 2014 at Auchi are depicted by Figures 1.5, 1.6, 1.7 and 1.8 respectively while plots of the calculated values of the Global Solar radiation against days for each of the four months are presented in figures 1.9, 1.10, 1.11 and 1.12 respectively.

IV. Results and Discussion

From tables 1.1 and 1.2, it can be observed that there is an overall slight increase in trend of the recorded mean maximum temperatures from January to March and then decreases in April with March recording the highest and April recording the lowest. This could be adduced to the fact the tropical continental air mass (CT) was withdrawing gradually during January to March and the sun was directly over head in the month of March while the month of April marked the unset of the rainy season. The observed average values of temperature difference (TD) between maximum and minimum temperatures show a slight linear widening from January to March (Figures 1.1, 1.2, 1.3 and 1.4). The linearity of the temperature difference (TD) is related to the relative humidity as noted by Hargreaves and Samani (1994). In essence, the increasing gap is a strong indicator of water vapor build up in the atmosphere and so a mark signal of linear increase in relative humidity. This gradual transit to rainy season has a linear effect of gradual widening of the gap in temperature difference (TD).

Viewing the calculated values of the extraterrestrial solar radiation in tables 1.5 and 1.6 comparatively, the highest extraterrestrial solar radiation value of 50.56 + 0.07MJ/m^2/day was recorded in April while the lowest value of 41.92 + 0.07MJ/m^2/day was recorded in January. An observable trend that was established between the four consecutive months under consideration was a gradual rise in the values of the extraterrestrial radiation from January to April. However, the values started decreasing from 22nd of April to 30th of April (see Figures 1.5, 1.6, 1.7 and 1.8). The implication of the trend is that extraterrestrial radiation increases steadily with days of the month from 1st January. The trend continues into April where it reaches its peak and then begin to decrease gradually. The region of continuous rise can be explained as period of increased temperature and dryness of atmosphere from the effect of the sun that is directly over head during the month of March and the departing tropical continental air mass (CT) known as harmattan. By the 21st of April to 22nd of April, the effect of the increasing temperature and dryness has reached the maximum and correspondingly, the effect of the setting in of rainy season takes over. This is characterized by cool moist wind known as the tropical maritime air mass (MT) from the coast. The wind contains aerosol that subsequently creates envelope that reduces the effect of further incidence of extraterrestrial radiation and so the downward trend results. The influence asserted by these climatic elements was observed by exell (2011) as "solar radiation passing through the atmosphere to the ground surface is known to be depleted through scattering, reflection, and absorption by the atmospheric constituents such as air molecules, aerosols, water vapour, ozone and clouds. The reflection of solar radiation is mainly by clouds and this plays an over riding part in reducing the energy density of the solar radiation reaching the earths surface". The obtained curvature may further be explained by the movement of the over head sun in the progress of the seasons. At the month of March and April, the sun is directly over head and not hitting the surface at angle in the geographical location of the research area, hence higher incidence of radiation are likely to be obtained. This assertion was justified by Babatunde (1988) who, reporting his works observed that "the encounter of solar radiation particularly with clouds leads to the variation in intensity of sun shine and the number of sun shine hours at the ground surface". He argued further that variation however is not only due to the clouds but also to the angle of incidence of the sun rays with the ground surface and its azimuth.

As can be observed from tables 1.5 and 1.6, the mean of the Global solar radiation varies between the minimum of

20.21 ± 0.04MJ/m^2/day in the month of January to the maximum of 25.03±0.04 MJ/m^2/day in March. The average Global solar radiation for the four months is 22.61 ± 0.04MJ/m^2/day. The maximum value of the global solar radiation of 26.65 ± 0.04MJ/m^2/day was recorded in March while the minimum of 18.57 ± 0.04MJ/m^2/day was recorded in the month of April. This can be linked to the fact that the maximum temperature difference (TD) was recorded during the month of March and the minimum in the month of April. Again, the established theory on the climatic factors resurfaces by this observation. A lot of fluctuations can be noticed in the plot of the global solar radiation against days in Figure 1.9, 1.10, 1.11 and 1.12 with the month of April showing the highest fluctuations. The wide gap between the two extremes in the month of April can be attributed to the change in climate from dry season to rainy season with its attendant cool, moist and aerosol laden winds as well as the gradual developing clouds.

Comparing the average global solar radiation of 22.61 ± 0.04 MJ/m^2/day (6.28 ± 0.01KWh/m^2/day) for the four months obtained in this work with similar work carried out by Offiong (2003), that reports an average solar radiation for Nigeria per day as a whole to be as high as 20MJ/m^2/day (5.56kwh/m^2/day) depending on the time of the year and location, it can be stated conveniently that the result obtained in this work is in strong agreement with his findings. In the same vain, similar work carried out for Kaduna in 2012 gives 23.49 ± 0.04MJ/m^2/day (6.53 ± 0.01KWh/m^2/day); for Ibadan in 2010, 13.77 ± 0.04MJ/m^2/day (3.83+_ 0.01KWh/m2/day); for Uturu in 2008, 8.82+_0.04MJ/m2/day (2.45+_ 0.01KWh/m2/day) and for Owerri in 1997, 13.58 ± 0.04MJ/m^2/day (3.77 ± 0.01KWh/m^2/day) Hassan and Onimisi (2013).

CONCLUSION

The global solar radiation at Auchi area of Nigeria within the period of study exhibits monthly variation, with mean values of 20.21, 22.89, 25.03 and 22.29 MJ/m^2/day respectively in the months of January, February, March and April, 2014. The average for the four months is 22.61MJ/m^2/day which is above the 20MJ/m^2/day benchmark of good average radiation level needed for radiant energy application for solar energy source (Offiong, 2003). Based on observation and the results obtained in this research work, the work has presented a good solar radiation application potential for Auchi Area of Nigeria. Despite the very great simplification, the model employed here appears to be well suited for the estimation of daily global solar radiation and can be applied to any area or location in Nigeria or even any part of the world. The main advantages of this model when compared to other estimation methods are that it uses only daily maximum and minimum temperatures, requires no special calibration parameters while weather station parameters are directly derived from the latitude. In addition to the above, the model provides a simple and low cost system for estimating solar radiations. It does not require expensive hardware for data processing nor information from neighbouring meteorological stations for spatial interpolation. The model is well suited for most agro-meteorological solar radiation data and can be used in areas where radiation is rarely measured by meteorological stations.

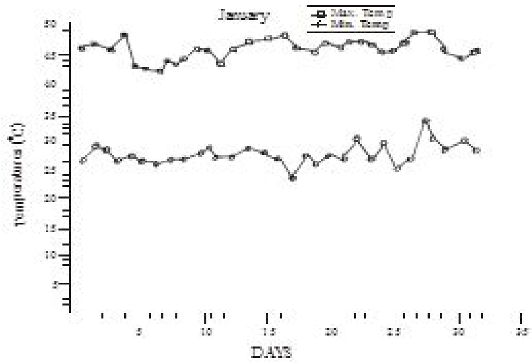

Fig. 1.1: Maximum and Minimum Temperatures for the Month of January 2014

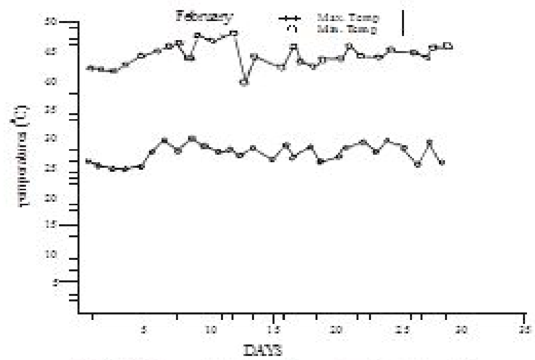

Fig. 1.2: Minimum and Minimum Temperatures for the Month of February 2014

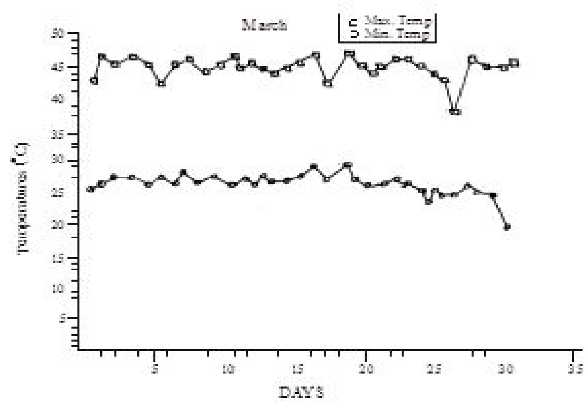

Fig. 1.3: Maximum and Minimum Temperatures for the Month of March, 2014

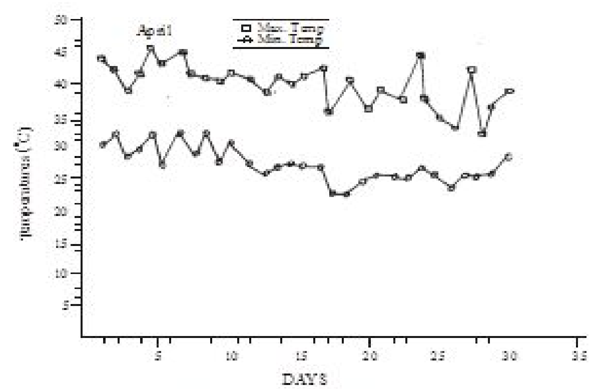

Fig. 1.4: Maximum and Minimum Temperatures for the Month of April, 2014

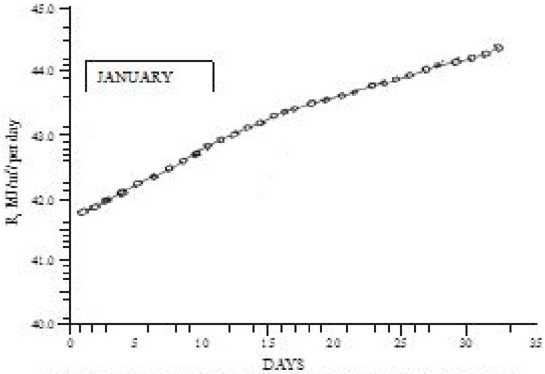

Fig. 1.5: Extraterrestrial Solar Radiation for the Month of January 2014

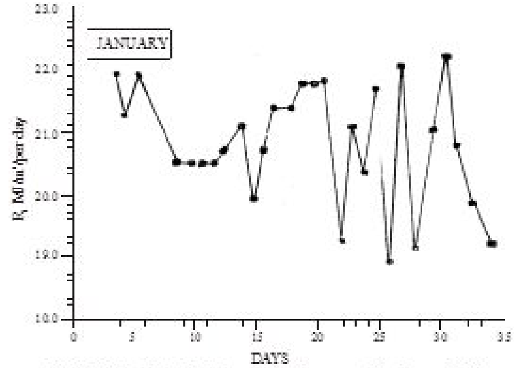

Fig. 1.9: Global Solar Radiation from 1st January to 31st January 2014

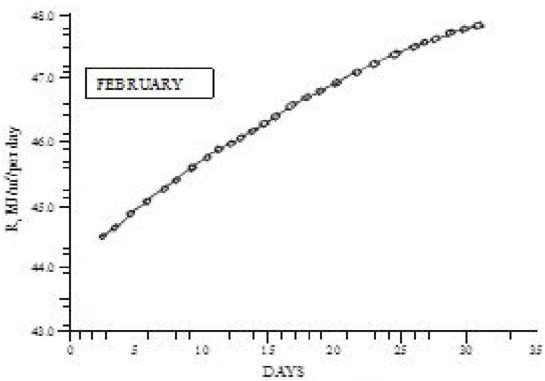

Fig. 1.6: Extraterrestrial Solar Radiation for the Month of February 2014

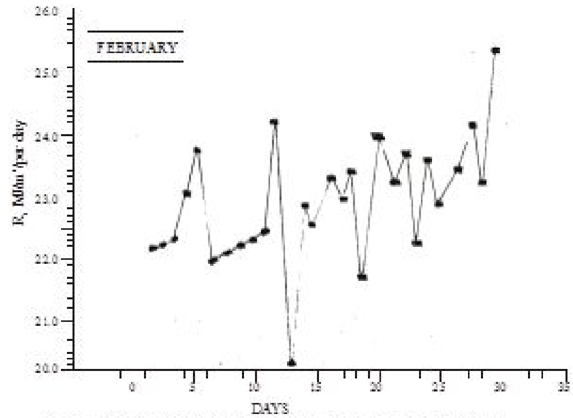

Fig. 1.10: Global Solar Radiation from 1st February to 28th February, 2014

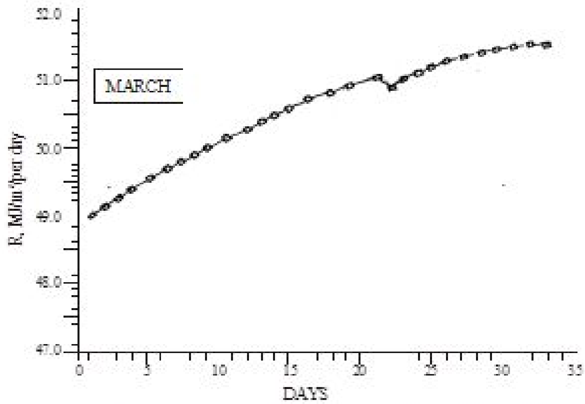

Fig. 1.7: Extraterrestrial Solar Radiation for the Month of March, 2014

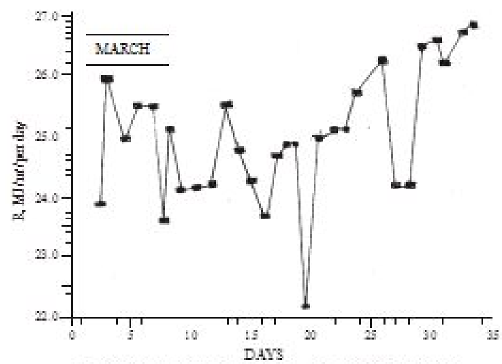

Fig. 1.12: Global Solar Radiation from 1st to 31st March, 2014

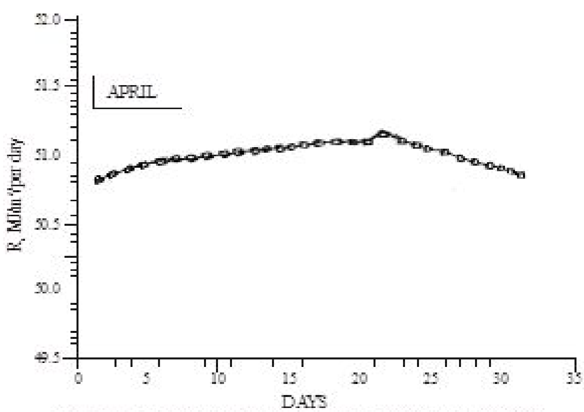

Fig. 1.8: Extraterrestrial Solar Radiation for the Month of April, 2014

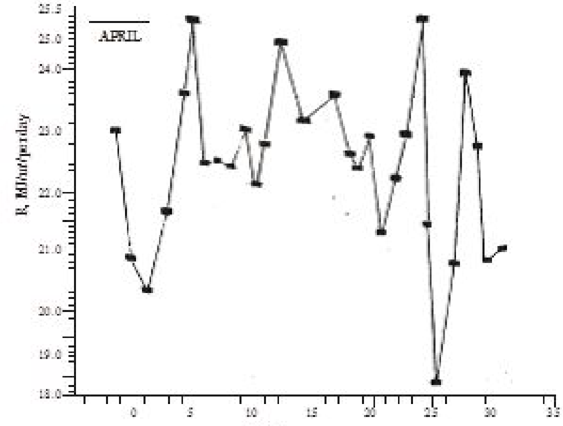

Fig. 1.12: Global Solar Radiation from 1st to 30th April, 2014

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