Research paper

Assessment of the Global Solar Energy Potential at Nigerian Defence Academy (NDA) Permanent Site Afaka Kaduna, Nigeria.

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Abstract; This paper assessed the global solar radiation potential in Nigerian Defence Academy, (NDA) permanent site Afaka Kaduna, North west Nigeria, for the period of March, April and May 2012. The cantonment lies exactly between longitudes 7° 12'E to 7° 35'E of the Greenwich meridian and latitude 10° 36'N to 10° 42'N of the equator. Procedure employed involved the use of Hargreaves-Samani's equation as a method of estimating solar radiation using minimum climatological data. The global solar radiation at NDA Kaduna within the period of study exhibits monthly variation, with mean values of 20.11±0.04, 20.14±0.04 and 20.18±0.04 MJm^{-2}Per day respectively. The study makes use of a statistical model that adopts the available data to assess the global solar radiation at NDA, permanent site Afaka, Kaduna for the months of March, April and May, 2012.The information from the studies conducted goes a long way to establish radiation data on the region studied which then forms a background for any planned application of solar radiation in the area. Meanwhile the information will also assist the policy makers in the academy to know exactly the particular days and time in the months under investigation when not to expose the military personnel and cadets to vigorous military training. Simply because it's the period of maximum sun shine in the region.

Key words; Solar radiation, Extraterrestrial radiation, Minimum and maximum Temperatures, Hargreaves-Samani's equation.

Introduction

Solar radiation is the main driving force of the processes in the atmosphere, as well as in the biosphere. Therefore, 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 (Nando, 2012). Comprehensive knowledge of global solar radiation of a particular location is a useful tool in study and design of the economic viability of devices that depends on use of solar energy. The trends of energy indicate that world oil production will reach peak and start a long downward slide when the fossil fuel and gas would have been consumed (Augustine and Nnabuchi, 2009). The studies that have gained speed on the new and renewable energy sources, are encouraged because energy resources used today are rapidly decreasing and cause environmental pollution. Solar radiation is the largest renewable energy source and it has been studied recently due to its importance (Ugwu and Ugwuanyi, 2011). The Knowledge of the dwindling level of these resources and their related environmental challenges is generating the necessity to shift emphasis from use of fossil fuels to the renewable energy resources such as solar radiation application.

Solar radiation is the radiant energy that is emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy. The knowledge of the amount of solar radiation in a given location (area) is essential in the field of solar energy physics. This in effect helps one to have a fair knowledge of the insulation power potential over the location. As a result of dwindling supply of natural gas, increase emphasis on the use of solar energy and other renewable energy sources in generating electricity should be developed. Bearing in mind the very well documented problems associated with other forms of energy, the use of solar energy should be paramount now. Solar energy is abundant, free and clean. Now 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 site becomes paramount. When that is done, the introduction and sustainability of solar energy technology will be assured (Chineke, 2002).

In this work, the Hargreaves equation were used to assess the global solar radiation at NDA permanent site Afaka, Kaduna, based on the available climatological parameters of measured maximum and minimum temperature. The study makes use of a statistical model that adopts the available data to assess the global solar radiation at NDA, permanent site Afaka, Kaduna for the months of March, April and May, 2012. Hence the aim of this work is to assess the global solar energy potential at NDA Permanent site Afaka Kaduna. Nigeria. Meanwhile this will assist the policy maker in the academy to know exactly the particular days and time in the months under investigation when not to expose the military personnel and cadets to vigorous military training. Offiong (2003) reported that the average solar

UNDER PEER REVIEW

radiation received in Nigeria per day is as high as 20MJ/m^2 depending on the time of the year and location. The sun emits energy at an extremely large and relatively constant rate; 24 hours per day, 365 days per year. If all of this energy could be converted into usable forms on earth, it would be more than enough to supply the world's energy demands. However, this is not possible because;

I. The earth intercepts only a small fraction of the energy that leaves the sun;

II. The earth rotates such that a collection device on the earth's surface is exposed to solar energy for only about half of each 24 hours period and;

III. Conditions of the atmosphere such as clouds and dust, sometimes significantly reduce the amount of solar energy reaching the earth's surface.

Weather patterns and other atmospheric conditions which scatter incoming rays also affect the rate at which solar energy reaches the earth's surfaces. The summation of the amount of solar energy arriving at a unit of area (m^2) during 1hour is called the solar radiation or insulation (U.S. technology white paper, 2006).

Research Area

The Nigerian Defence Academy (NDA) permanent site is located in Igabi local Government area of Kaduna state. The cantonment lies exactly between longitudes 7° 12'E to 7° 35'E of the Greenwich meridian and latitude 10° 36'N to 10° 42'N of the equator. The cantonment is bounded to the North by the Kaduna international airport, to the south by the National Forestry Research Institute, to the East by Mando settlement and to the West by the vast farmland.

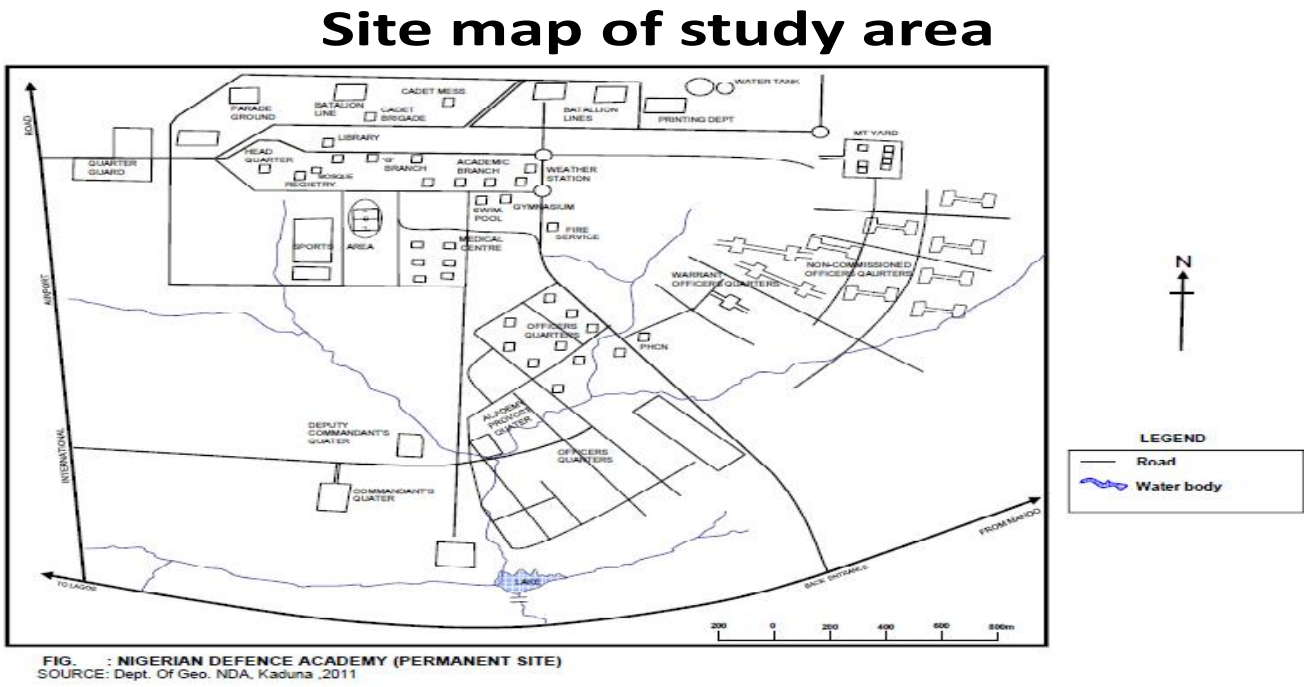


Figure1. Site map of Nigerian Defence Academy, Kaduna.

Methodology

For the purpose of this research work, Hargreaves method is employed. The temperatures data were recorded for a period of three months from Nigerian Defence Academy (NDA) meteorological station, Kaduna. The maximum and minimum thermometers were used for observing the maximum and minimum temperatures.

Maximum and minimum thermometers were placed in the chamber of the Stevenson screen and readings were taken at 09:00h GMT (10am local time) in conformity with world meteorological standard time of reading in synoptic hours. This measurement was taken once every day for three months, starting from first day of March through April and ending of May .The thermometers were placed horizontally inside the Stevenson screen which shelters them and helps to prevent interference by rain, dew and sun's direct rays. The Stevenson screen is painted white so that it would reflect sunlight. It has louvers sides so as to ensure free movement of air in and out of the Stevenson screen and to ensure that the temperature inside and outside the Stevenson screen are the same. The Stevenson screen was raised to a height of some meters above the ground at Nigerian Defence Academy, Kaduna meteorological site. The reading of the daily temperature variables that is, the maximum and minimum temperatures were taken at 10 am prompt.

Data treatment

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

$$R_s = K_r\,(T_{max} - T_{min})^{0.5}\,R_a \qquad (1)$$

Where, T_{max} and T_{min} = mean daily maximum and minimum air temperature (^{0}C) for period (generally one month), R_a = extraterrestrial radiation and k_r = empirical coefficient. Units of R_s and R_a are the same. Initially, K_r was set to 0.17 for arid and semiarid climates. Hargreaves (1994) later recommended using K_r = 0.16 for interior regime and K_r = 0.19 for coastal regime. Kaduna, being located in an interior position, the K_r value applied is 0.16.

The extraterrestrial radiation ($R_{a,\ MJm^{-2}d^{-1}}$) can be calculated for any given day of the year and latitude according to equations from Duffie and Beckman (1980) .

$$R_a = \frac{1440}{\pi}\,[G_{sc}.dr]\,[\psi_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\psi_s)] \qquad (2)$$

where,

G_{sc} = solar constant ($0.0820 MJm^{-2}min^{-1}$), dr = inverse relative distance from earth to sun, ψ_s = sunset hour angle (rad), φ = latitude (rad) and δ = solar declination (rad).

In the above equation, the daily values of φ, dr, δ and ψ_s are given by the following equations;

$$dr = 1 + 0.033\cos\left[\frac{2\pi JD}{365}\right] \qquad (3)$$

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

$$\psi_s = \mathrm{arCos}\,(-\tan\varphi\tan\delta) \qquad (5)$$

where JD = day of the year.

All data obtained was further treated statistically, using appropriate graphs and tables. Graphs were specifically constructed to convey information on the changes of the T_{max} and T_{min}. This is required to offer a constructive guidance on the data interpretation in line with the set objectives.

UNDER PEER REVIEW

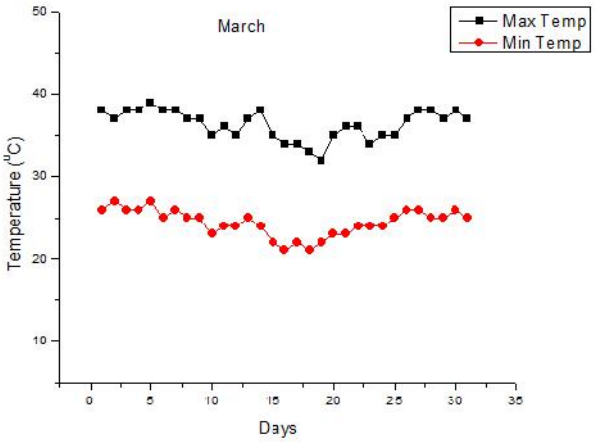
Results and Discussion

The results are hereby treated in units of temperature readings and radiation readings for the months under consideration.

Table 1. Temperature readings for the months under consideration

	March, 2012				April, 2012				May, 2012			
Day	Tmax.(^{0}C)	Tmin. (^{0}C)	T.D	T.a	Tmax. (^{0}C)	Tmin. (^{0}C)	T.D	T.a	Tmax. (^{0}C)	Tmin. (^{0}C)	T.D	T.a
1	38.0	26.0	12.0	32.0	38.0	25.0	13.0	31.5	35.0	24.0	11.0	29.5
2	37.0	27.0	10.0	32.0	39.0	27.0	12.0	33.0	35.0	23.0	12.0	29.0
3	38.0	26.0	12.0	32.0	40.0	27.0	13.0	33.5	32.0	25.0	7.0	28.5
4	38.0	26.0	12.0	32.0	38.0	26.0	12.0	32.0	36.0	24.0	12.0	30.0
5	39.0	27.0	12.0	33.0	37.0	25.0	12.0	31.0	35.0	24.0	11.0	29.5
6	38.0	25.0	13.0	31.5	37.0	24.0	13.0	31.5	33.0	22.0	11.0	27.5
7	38.0	26.0	12.0	32.0	37.0	24.0	13.0	30.5	34.0	23.0	11.0	28.5
8	37.0	25.0	12.0	31.0	37.0	25.0	12.0	31.0	34.0	22.0	12.0	28.0
9	37.0	25.0	12.0	31.0	36.0	24.0	12.0	30.0	33.0	23.0	10.0	26.0
10	35.0	23.0	12.0	29.0	35.0	24.0	11.0	29,5	33.0	24.0	9.0	26.5
11	36.0	24.0	12.0	30.0	33.0	22.0	11.0	27.5	32.0	23.0	9.0	27.5
12	35.0	24.0	12.0	29.5	34.0	23.0	11.0	28.5	33.0	23.0	10.0	28.0
13	37.0	25.0	12.0	31.0	34.0	22.0	12.0	28.0	33.0	21.0	12.0	27.0
14	38.0	24.0	14.0	31.0	33.0	23.0	10.0	28.0	30.0	22.0	8.0	26.0
15	35.0	22.0	13.0	28.5	33.0	24.0	9.0	28.5	30.0	21.0	9.0	25.5
16	34.0	21.0	13.0	27.5	32.0	23.0	9.0	27.5	31.0	21.0	10.0	26.0
17	34.0	22.0	12.0	28.0	30.0	21.0	9.0	25.5	33.0	22.0	11.0	27.5
18	33.0	21.0	12.0	27.0	31.0	22.0	9.0	26.5	32.0	21.0	11.0	26.5
19	32.0	22.0	10.0	27.0	32.0	23.0	9.0	27.5	34.0	22.0	12.0	28.0
20	35.0	23.0	12.0	29.0	33.0	23.0	10.0	28.0	31.0	23.0	8.0	27.0
21	36.0	23.0	13.0	29.5	33.0	23.0	10.0	28.0	33.0	23.0	10.0	28.0
22	36.0	24.0	12.0	30.0	30.0	22.0	8.0	26.0	32.0	22.0	10.0	27.0
23	34.0	24.0	10.0	29.0	30.0	21.0	9.0	25.5	34.0	24.0	10.0	29.0
24	35.0	24.0	11.0	29.5	31.0	21.0	10.0	26.0	38.0	26.0	12.0	32.0
25	35.0	25.0	10.0	30.0	33.0	22.0	9.0	27.5	37.0	24.0	13.0	30.5
26	37.0	26.0	11.0	31.5	32.0	21.0	11.0	26.5	36.0	23.0	13.0	34.5
27	38.0	26.0	12.0	32.0	34.0	22.0	12.0	28.0	36.0	23.0	13.0	29.5
28	38.0	25.0	13.0	31.5	35.0	23.0	12.0	29.0	31.0	22.0	9.0	26.5
29	37.0	25.0	12.0	31.0	35.0	24.0	11.0	29.5	32.0	21.0	11.0	26.5
30	38.0	26.0	12.0	32.0	31.0	23.0	8.0	27.0	32.0	22.0	10.0	27.0
31	37.0	25.0	12.0	31.0	-	-	-	-	32.0	23.0	9.0	27.5
Mean	**36.3**	**24.4**	**11.9**	**30.4**	**34.1**	**23.3**	**10.7**	**28.7**	**33.3**	**22.8**	**10.5**	**28.1**
Max.	**39.0**	**27.0**	**14.0**	**33.0**	**40.0**	**27.0**	**13.0**	**33.5**	**38.0**	**26.0**	**13.0**	**34.5**
Min.	**32.0**	**21.0**	**10.0**	**27.0**	**30.0**	**21.0**	**8.0**	**25.5**	**30.0**	**21.0**	**7.0**	**25.5**

UNDER PEER REVIEW



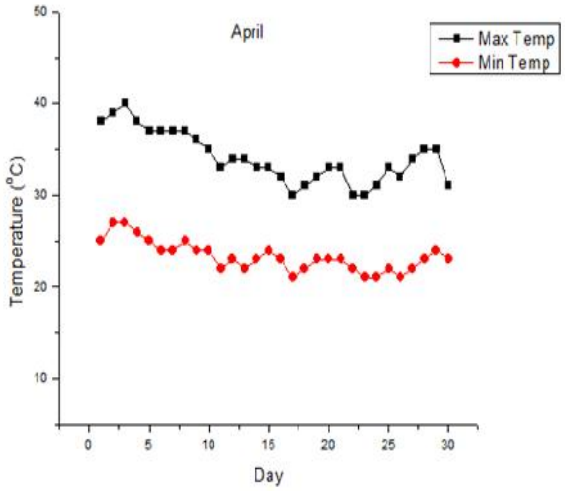


Figure 2. Max and Min temp. for the month of March,2012.

Figure 3. Max and Min temp. for the month of April,2012.

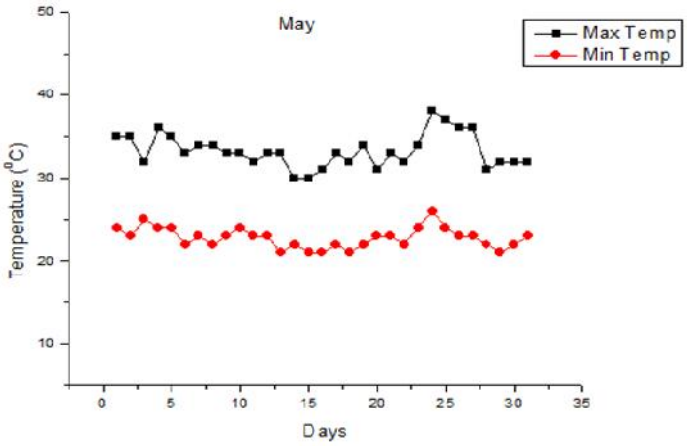


Figure 4. Max and Min temp. for the month of May,2012.

Table 2. Summary of the temperature values.

	March,2012			April,2012			May2012		
	Tmax.(^{0}C)	Tmin.(^{0}C)	TD	Tmax. (^{0}C)	Tmin. (^{0}C)	TD	Tmax.(^{0}C)	Tmin. (^{0}C)	TD
Mean	36.29	24.41	11.9	34.1	23.3	10.73	33.29	22.77	10.52
Max.	39.0	27.0	14.0	40.0	27.0	13.0	38.0	26.0	13.0
Min.	32.0	21.0	10.0	30.0	21.0	8.0	30.0	21.0	7.0

Table 2 shows a compacted summary of measured and evaluated values of temperature as obtained in the research site in the months of March, April and May, 2012. It can be seen that an overall slight reduction in trend is recorded in the mean maximum temperatures between the observed months with the month of May recording the least mean value. This could be adduced to transit period of the season from the dry to unset of rain season. The observed averaged values of temperature difference (TD) between maximum and minimum temperatures show a linear widening from March to May. The linearity of the temperature difference (TD) is related to relative humidity as noted by Hargreaves and samani, (1982). In essence, the increasing gap is a strong indicator of water vapour builds up in the atmosphere and so a marked signal of linear increase in relative humidity. Thus, the gradual transit to rain season has a linear effect of gradual widening of the gap in TD. A general view of the temperature range yields narrow merging. The narrowness in the temperature range can be explained by clearness of the sky; a large range of values could have been a reflection of indices like high and variable cloud cover as noted by Jennifer (2004). With a close sensitivity to Jagtap's statement on factors that influence the difference in maximum and minimum temperatures in a given location (Jagtap 1993) in which the researcher observed that "other than solar radiation, cloudiness and humidity, maximum and minimum temperatures in a given location can be influenced by latitude, elevation, topography, storm pattern, advection and proximity to a large body of water". It can then be safely stated that the major factors at play in this particular location of research are the absence of cloud which is characterized by clear sky and humidity factor resulting from the gradual change of season.

The value of the daily extraterrestrial radiation on a horizontal surface calculated for the months of March, April and May of the year 2012' outside the earth's atmosphere at NDA are depicted by Figures 8, 9 and 10.

Viewing the observations for the three months comparatively, the highest extraterrestrial solar radiation value was recorded in the month of May with a value of 38.55± 0.07MJm^{-2}day^{-1} and the lowest value was obtained in the month of March with the value of 34.47± 0.07MJm^{-2}day^{-1}. An observable trend was established between the three consecutive months under consideration; there is a gradual rise in value of the extraterrestrial radiation from the month of March. This trend presents a continuation of the plot in the Month of April. The trend is maintained in the month of May reaching a climax at the maximum stated above. From the maximum value, we recorded a flat portion of the scene where there occurred constant extraterrestrial radiation values for some length of days before a down slope took over the trend. Merging the scenario developed by the extraterrestrial radiation values for the three months, it can be observed that a progressive increase were obtained that seemed to be linked together.

UNDER PEER REVIEW

Table3. Calculated Radiation Values for the months under consideration

	March, 2012				April, 2012				May, 2012			
Day	D Year	T D	Ra(MJm^{-2} Per day)	Rs(MJm^{-2} Per day)	D Year	T D	Ra(MJm^{-2} Per day)	Rs(MJm^{-2} Per day)	D Year	TD	Ra(MJm^{-2} Per day)	Rs(MJm^{-2} Per day)
1	61	12	34.47	19.34	92	13	37.39	21.84	122	11	38.49	20.68
2	62	10	34.59	17.72	93	12	37.45	21.02	123	12	38.50	21.61
3	63	12	34.70	19.47	94	13	37.51	21.91	124	7	38.51	16.51
4	64	12	34.81	19.53	95	12	37.57	21.08	125	12	38.52	21.62
5	65	12	34.93	19.60	96	12	37.63	21.12	126	11	38.53	20.70
6	66	13	35.04	20.47	97	13	37.69	22.01	127	11	38.53	20.70
7	67	12	35.15	19.73	98	13	37.74	22.04	128	11	38.54	20.71
8	68	12	35.26	19.79	99	12	37.80	21.21	129	12	38.54	21.63
9	69	12	35.37	19.85	100	12	37.85	21.24	130	10	38.55	19.75
10	70	12	35.47	19.91	101	11	37.90	20.36	131	9	38.55	18.74
11	71	12	35.58	19.97	102	11	37.94	20.38	132	9	38.55	18.74
12	72	12	35.68	20.02	103	11	37.98	20.41	133	10	38.55	19.75
13	73	12	35.79	20.08	104	12	38.03	21.34	134	12	38.55	21.63
14	74	14	35.89	21.75	105	10	38.07	19.50	135	8	38.55	17.66
15	75	13	35.99	21.02	106	9	38.11	18.52	136	9	38.55	18.74
16	76	13	36.08	21.07	107	9	38.15	18.54	137	10	38.54	19.74
17	77	12	36.18	20.30	108	9	38.18	18.56	138	11	38.54	20.71
18	78	12	36.27	20.35	109	9	38.21	18.57	139	11	38.54	20.71
19	79	10	36.36	18.63	110	9	38.24	18.58	140	12	38.53	21.62
20	80	12	36.46	20.46	111	10	38.27	19.61	141	8	38.53	17.65
21	81	13	36.54	21.34	112	10	38.30	19.62	142	10	38.52	19.73
22	82	12	36.63	20.56	113	8	38.32	17.56	143	10	38.52	19.73
23	83	10	36.71	18.81	114	9	38.35	18.64	144	10	38.51	19.73
24	84	11	36.80	19.77	115	10	38.37	19.66	145	12	38.50	21.61
25	85	10	36.88	18.89	116	9	38.40	18.66	146	13	38.50	22.49
26	86	11	36.96	19.86	117	11	38.41	20.64	147	13	38.49	22.48
27	87	12	37.04	20.79	118	12	38.43	21.57	148	13	38.49	22.48
28	88	13	37.11	21.68	119	12	38.45	21.58	149	9	38.48	18.70
29	89	12	37.18	20.86	120	11	38.46	20.66	150	11	38.47	20.67
30	90	12	37.25	20.90	121	8	38.48	17.63	151	10	38.46	19.70
31	91	12	37.32	20.94	-	-	-	-	152	9	38.45	18.69
Mean	**76**	**12**	**36.02**	**20.11**	**107**	**11**	**38.06**	**20.14**	**137**	**11**	**38.52**	**20.18**
Max.	**91**	**14**	**37.32**	**21.75**	**121**	**13**	**38.48**	**22.04**	**152**	**13**	**38.55**	**22.49**
Min.	**61**	**10**	**34.47**	**17.72**	**92**	**8**	**37.39**	**17.56**	**122**	**7**	**38.45**	**16.51**
Error =			± 0.07	± 0.04								

UNDER PEER REVIEW

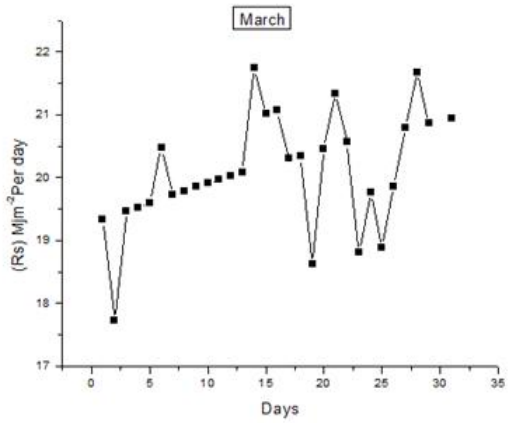


Figure 5. Global solar radiation from 1st to 31st March, 2012.

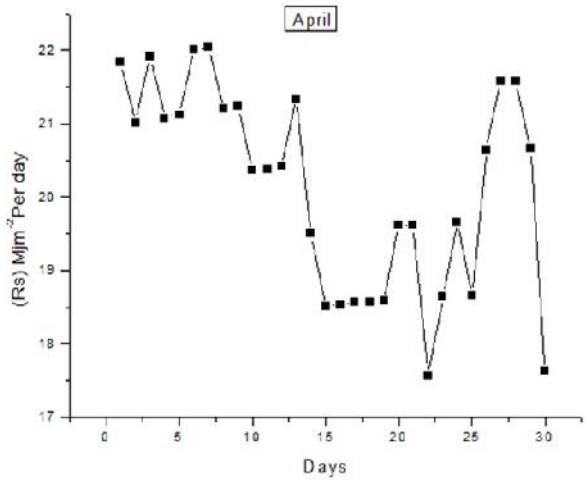


Figure 6. Global solar radiation from 1st to 30th April, 2012.

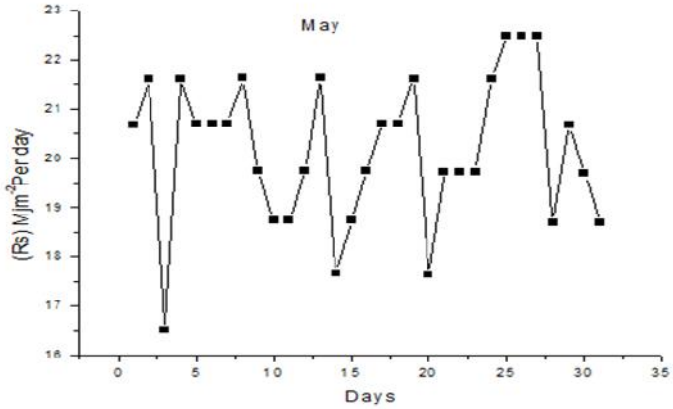


Figure 7. Global solar radiation from 1st to 31st May, 2012.

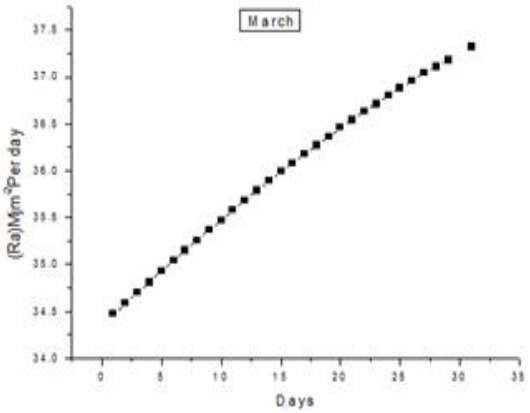


Figure 8. Extra. Solar radiation for the month of March, 2012.

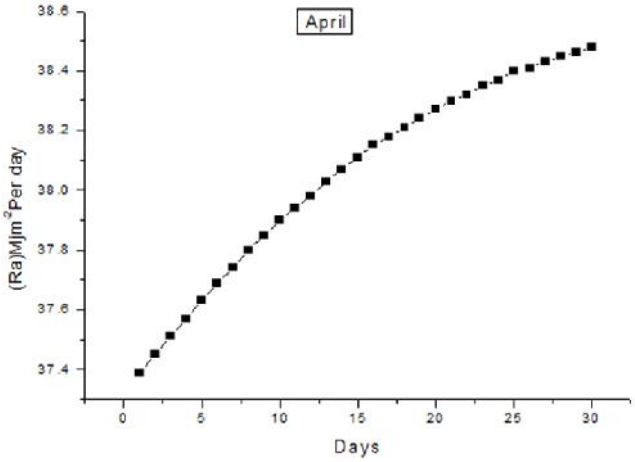


Figure 9. Extra .Solar radiation for the month of April,2012.

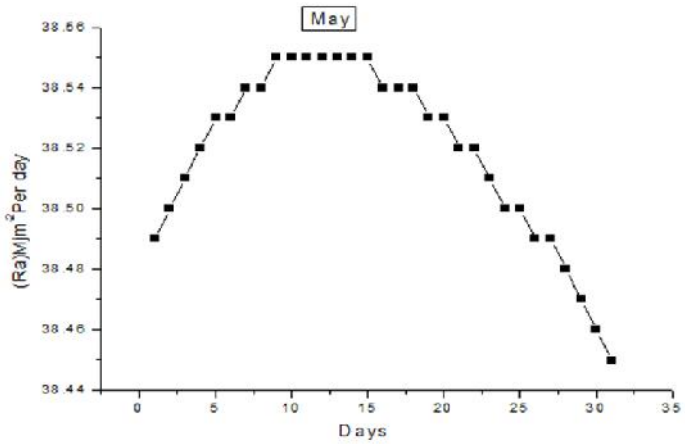


Figure 10. Solar radiation for the month of May, 2012.

Table 4. Summary of Radiation Values

	March,2012		April,2012		May,2012	
	Ra (MJm^{-2}Per day)	Rs (MJm^{-2}Per day)	Ra (MJm^{-2}Per day)	Rs (MJm^{-2}Per day)	Ra (MJm^{-2}Per day)	Rs (MJm^{-2}Per day)
Mean	36.02	20.11	38.07	20.14	38.52	20.18
Max.	37.32	21.75	38.48	22.04	38.55	22.49
Min.	34.47	17.72	37.39	17.56	38.45	16.51

The implication of the trend is; extraterrestrial radiation increases steadily with days of the month from the 1st day of March, the trend continues into April and subsequently into May until it began to reach a pick where it remains constant for days and finally it takes a gradual deep downwards. The regions of continuous rise can be explained as period of increased dryness of atmosphere from the effect of the departing cold weather which is characterized by haze, mist fog and dust all of which contributes to shade for the solar radiation to deliver its full strength on the surface. By the 9th - 15th of May, the effect of the increasing dryness as reached the maxima and correspondingly the effect of the setting in of 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. The influence asserted by these climatic elements was observed by Exell(2000) 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 like air molecules, aerosols, water vapour, ozone and 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."

UNDER PEER REVIEW

The obtained curvature may further be explained by the movement of the overhead sun in the progress of the seasons. At the Months of March, April and early May, sun is directly overhead and not hitting the surface at angle in the geographical location of the research area, hence higher incidence of radiation are likely to be obtainable. The stated assertion was justified by Babatunde (Babatunde 1988) in reporting his works. He observed that "the encounter of solar radiation particularly with clouds lead to the variation in intensity of sunshine and the number of sunshine hours at the ground surface: He argued further that the variation however is not only due to the clouds but also to the angle of incidence of the sun's rays with the ground surface and its azimuth."

The values of Global solar radiation for the three months of the year under study were obtained and tabulated in tables 3 and 4. Plots of Global radiation against days for each of the month are presented in figures 5, 6 and 7. Figure 5 shows a steady rise in global solar radiation representing March measured outputs, by the month of April, an overall constant result were obtained, though with fluctuations here and there. This is depicted by figure 6. Numerically, the maxima range from 21.75-22.49±0.04MJ/m^2/day between March and May. The period of minimum solar radiation was recorded between April and May and range between 16.51- 17.56± 0.04MJ/m^2/day. A close observation reveals that the peak of the maxima and minima values of Global solar radiation both fell to the same month of May. An implication of this is that it relates directly to the maximum temperature gap registered earlier. Again, the established theory on the climatic factors resurfaces by this observation. The wide gap between the two extremes can safely be linked 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 this result of maximum global radiation of value 22.49± 0.04MJ/m^2/day, to results of similar works carried out at Uturu in 2008 by Chiemaka, chineke at umudike in 2007 and chineke at Owerri in 2002, the outputs of solar radiation obtained in this work is higher than the output obtained in their works. In the same vein, a related work carried out in south-western state of Ibadan yields Global radiation values of range 10.62 and 16.91 MJm^{-2}day^{-1}. With reference to Offiong (2003) that reports an average solar radiation for Nigeria per day as a whole to be as high as 20Mj/m^2 depending on the time of the year, it can be stated conveniently that the result obtained in this work is in strong agreement with his findings. Approximating this result in percentage of Offiong's observation, a strong correlation of 88.9% agreement of his result was obtained.

UNDER PEER REVIEW

Conclusions

The global solar radiation at NDA Kaduna within the period of study exhibits monthly variation, with mean values of 20.11±0.04, 20.14±0.04 and 20.18±0.04 MJm^{-2}Per day respectively in the months of March, April and May of study, all of which shoot above Offiong's benchmark of good average radiation level needed for radiant energy application for energy source. Based on observation and results obtained, the research has presented a good solar radiation application potential for NDA Kaduna. Despite the very great simplification, the model employed here appears to be well suited for the estimation of daily global solar radiation records. The principal advantages of this model in respect to other estimation methods are that it uses only daily maximum and minimum temperature records, requires no special calibration parameters while weather station parameters are directly derived from the latitude. In addition to the stated advantages, the model provides a simple and low cost system for estimating solar radiation. It does not require information from neighboring stations for spatial interpolation and it does not require expensive hardware for data processing. The model appears to be suited for most agro-meteorological and simulation studies requiring solar radiation data and it can extend the effectiveness of these applications to areas where radiation is not or is only rarely measured by meteorological networks.

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UNDER PEER REVIEW

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