GLOBAL SOLAR RADIATION DISTRIBUTION AND UTILIZATION SEASONS AT ILORIN, NIGERIA

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Abstract

Analysis of a two year (September 1992 - August 1994) data set on global solar radiation have been carried out for a tropical location, Ilorin, Nigeria (8°32'N, 4°32'E, 375m above sea level). In addition to simple analysis on average values, tables and figures of cumulative frequency distribution, maximum / consecutive number of days above certain insolation values and solar utilization season lengths above various selected energy levels during the yearly cycle are presented. Results are presented on monthly and annual periods for ease of perusal and possible application purposes. And show that Ilorin has high insolation values and long solar utilization seasons of up to 365days in the year at energy levels as high as 10- 15MJm^{-2}.

Keywords: *Statistical analysis, global solar radiation and Ilorin*

1 Introduction

The successful development of projects concerned with the practical utilization of global solar radiation depends to some extent, upon increasing our knowledge of solar and sky radiation in different climates. The availability of data regarding solar radiation of any place is an essential prerequisite for deciding the techno-economic feasibility of solar energy utilization and subsequent design of the equipment (Al-Riahi *et al.*, 1992).

Some concentrating systems, for instance, require information on the direct beam component whereas the tilted plane surface requires the diffuse component. Proper sizing of almost all solar systems require the probability of the expected number of days with global solar radiation above or below certain threshold values. In some specialized applications, the number of consecutive days above or below a given threshold value of solar radiation is an important factor especially where energy storage for several days is needed, (Close, 1967 and Duffie and Beckman, 1980).

Many engineering problems are solved with the use of long term averages of radiation data called the mean values. Statistical analysis enables primary data set to be reformed into a manner which is not only concise and convenient but more informative than the original data. For solar energy utilization, there is need for accurate scientific assessment of the resources to establish its potential at a specific location and for the design of an economical and efficient solar system, we require much more than the simple knowledge of arithmetic mean. Detail statistics of the intensity and distribution of solar radiation are required (Raja and Twideli, 1994).In the present study, monthly averages of hourly totals of global solar radiation on a horizontal surface were analyzed along with seasonal variations. The monthly average global solar radiation for each hour of the day are presented and studied including their cumulative frequency distribution. Also presented are consecutive number of days above or below certain threshold values and solar utilization season for selected threshold values of solar radiation. Details concerning the geography of the site can be obtained in Udo and Aro (1999) and Udo (2002).

2. Methods and Database

The data cover a period of two years: September, 1992 to August,1994. The radiometer used in measuring the global solar radiation was Precision Spectral Pyranometer (model Eppley - PSP). Only measurements taken between 07.00 hours and 19.00 hours of the local standard time (LST) were used because radiation rates outside this time interval showed negligible values even during the dry season period. Details concerning this radiometer and others used at the site are as contained in Udo and Aro, (1999) and Udo, (2002).

Although a two-year data analysis seems a bit inadequate for major climatological conclusions to be drawn, an earlier work Udo (2000) has shown that the small duration posses no major limitations to the conclusions derivable.

In this work emphasis is on Arithmetic means, cumulative frequency distribution and number of days/consecutive days in which insolation is above or below a certain threshold value. However, where necessary, data on seasonal and diurnal variation which had earlier been reported in Udo and Aro (1999) and Udo and Aro (2000) respectively will be highlighted. The above parameters are briefly explained below.

3. Simple Arithmetic Means

Even though the arithmetic means are highly sensitive to extreme values in a range of data like those of solar radiation which is highly variable, it is the most widely used because of its ability to provide a rough estimate of solar radiation utility of a place. Monthly average values of solar radiation on a horizontal surface are presented on a tabular form.

3.1 Cumulative frequency distribution (CFD)

The availability of solar radiation and the frequency of distribution of days with various threshold values can be used to determine the possibility of the utilization of solar energy especially in the areas of planning and sizing of solar appliances. (Al-Riahi *et al.*,1992, Raja and Twideli,1994, Akrawi *et al.*,1986). The cumulative distribution is obtained usually by arranging the data in descending or ascending order and to construct the cumulative frequency distribution, the average daily distribution in each month over the period under study is again arranged in descending or ascending order. With a class interval of $1 MJm^{-2}$ the range is placed in the first column of the frequency table. The next thirteen columns, one for each month and one for annual mean values are filled by counting the number of days n(i) on which the daily insolation falls in the interval:

$$i\, MJm^{-2} < H < (i+1)\, MJm^{-2}, \qquad (1)$$

and the n(i) for each interval are added to give the mean number of days d(i) per month for which insolation is above a threshold value of $j MJm^{-2}$

I.e.

$$d(j) = P/N\,{}^{k}_{i=1}n(i) \qquad (2)$$

where N is the number of observations and P is the total number of days in the month or year as the case may be. If in the other hand we wish to obtain the number of days below certain values we do a simple mathematical subtraction of the frequency of days d (j) of the j^{th} interval in question from total number of days, P in the month or year as follows:

$$d'(j) = P \;\; d(j) \qquad (3)$$

In the same way the number of days that lie below or above a specified range of intervals can be obtained from the frequency table or

$$d(i,k) = d(k) - d(i) \qquad (4)$$

where solar radiation is in the interval between the i^{th} and k^{th} term.
i.e. $iMJm^{-2} < H < kMJm^{-2}$

3.2 Consecutive number of days

The need for storage or auxiliary heating for those times when solar radiation values fall below solar system's efficiency threshold during a solar utilization season requires that the maximum number of days or consecutive number of days for which one will require this service be known. The solar utilization season for a particular radiation threshold is defined as that period between the average first and last date exceeding the threshold value. As with cumulative frequency distribution, a class interval of 1 MJm^{-2} per day is maintained. The maximum number of days for each class interval is counted starting from the lowest values for each month.

4. Results and Discussion

In this work, the following analysis was carried out. (a) Average solar radiation (b) cumulative frequency distribution and (c) maximum / consecutive number of days with insolation above or below a defined threshold value.

4.1 Average values

Figs. 1 and 2 shows the hourly average global solar radiation on a horizontal surface. We note that:

(a) Global solar radiation reaches its maximum for each of the months of the year at 13.00 hour local standard time (LST) which is about solar noon except in the month of June when it occurred at 14.00hours (LST). As earlier observed by Udo and Aro (2000), this is likely to be due to the presence of convective clouds which are common around solar noon but disappear a little later.

(b) The highest and lowest solar noon values were 3.07MJm^{-2} in March and 1.93MJm^{-2} in August, a factor of 1.6. The seasonal and diurnal variation of this parameter had earlier been reported in Udo and Aro (1999) and Udo and Aro (2000) respectively.

(c) The hourly variation of global solar radiation is asymmetrical with regards to solar noon, threshold values before noon are slightly less than those occurring after noon.

(d) The yearly average daily total global solar radiation is 17.22MJm^{-2}

(e) High values of global solar radiation are associated with those months when the atmosphere has less clouding activities and hamattan dust is just setting in or clearing off. This again highlights the importance of atmospheric conditions to solar radiation as seen by the sharp variation from one season to the other. Minimum values between July and August are due to heavycloudiness of the sky during the rainy season and minimum values occurring between December and January are due to increased harmattan haze in the sky and increased aerosols in the sky due to bush burning activities common in Ilorin at this time of the year.

(f) Table 1 shows the percentage distribution of daily radiation between the peak hours of 10.00 - 15.00hours (LST) and the rest of the day.

(g) A yearly average of 11.5 MJm^{-2} per day representing 67.3% of radiation falls within the peak period of 10.00 - 15.00 hours (LST)and only about 5.6MJm^{-2} representing 32.7% .is received during the rest of the day. The highest insolation during this period is in December (about 11.57 MJm^{-2} representing 70.8%) and the lowest occurs in August (about 8.69MJm^{-2} representing 63.4% only.

4.2 Cumulative frequency distribution (CFD)

Table 2 is a cumulative frequency distribution of global solar energy at Ilorin These values are displayed in Figs. 3 and 4. From Table 2 for example, we notice that 14MJm^{-2} of global solar radiation is expected daily for 26days in the month of April and 295days over the year.We can determine the number of days of insolation below 14MJm^{-2} over the course of the year from eqn. 3 as follows:

$$d'(j) = P \ d(j)$$

or $d'(j) = 365 \ 295 = 70$ days

If we wish to know the number of days that lie below or above a particular range, we can apply eqn. (4). For example, total number of days of solar radiation lying between 10MJm^{-2} and 20MJm^{-2} in the month of March can be obtained as follows:

$$d(10, 20) = 30.5 - 19.0 \text{ (see Table 2)}$$
$$= 11.5$$
or $= 12$ days

4.3 Maximum / consecutive number of days of insolation

Table 3 is a construction of the maximum number of consecutive days with insolation above a certain threshold. Table 3 indicates solar utilization season lengths above various selected energy levels during the yearly cycle. Dots at the beginning and end of the graph are normally indicated to show the dates in which solar threshold values begin and end for individual years of study. This can be determined from Table 3 for example, we find 5 days without solar radiation below 15MJm^{-2} in January. In Table 4, we can see solar utilization seasons for some global solar radiation threshold values.

5. Summary and Conclusion

The cost analysis of the investment in solar system installation is largely dependent- on accurate inputs of properly organized data. For Ilorin, the following inputs may be a necessary source of information.

1. Annual average daily global solar radiation is 17.22 MJm^{-2}.

2. In terms of hourly average, there are double maxima of 3.07 Mjm^{-2} (primary) in March and 2.80 MJm^{-2} (Secondary) in October both occurring at 13.00 hours (LST) except in the month of June in which it occurred at14.00 hours (LST).

Table 1: Percentage distribution of daily radiation(GMT)

Month	(10-15) hr	Percentage(%)	Rest of the hrs.	Percentage(%)
January	11.21	70.00	4.81	30.00
February	11.21	68.40	5.98	31.60
March	11.21	68.20	6.39	31.80
April	11.21	66.20	6.57	33.80
May	11.21	65.80	6.34	34.20
June	11.21	64.80	6.03	35.20
July	11.21	63.70	5.04	36.30
August	11.21	63.40	5.02	36.60
September	11.21	66.60	5.21	33.40
October	11.21	69.30	5.55	30.70
November	11.21	70.10	5.33	29.90
December	11.21	70.80	4.74	29.20
Average	11.21	67.28	5.58	32.73

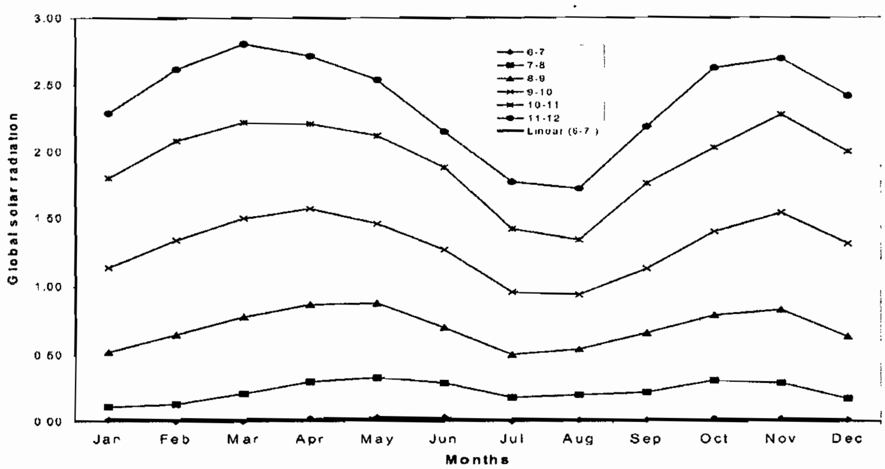

Fig. 1: Monthly average hourly global radiation for 7-13 hours (GMT)

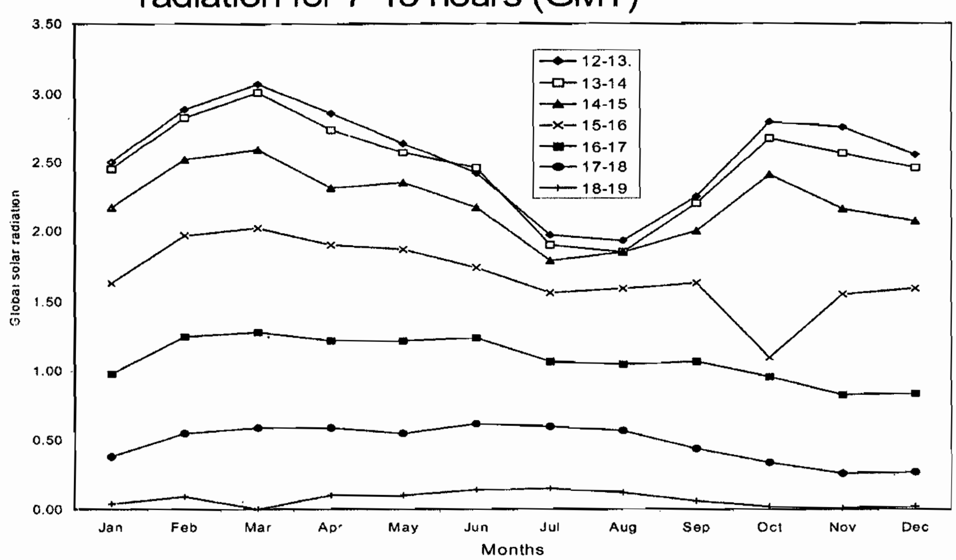

Fig. 2: Monthly average hourly global radiation for -12 - 19 hours

Table2: Cumulative frequency distribution

G	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.0	31.0	28.0	31.0	30.5	31.0	30.5	31.0	31.0	30.0	31.0	30.0	31.0
2.0	31.0	28.0	31.0	30.5	31.0	30.5	31.0	31.0	30.0	31.0	30.0	31.0
3.0	31.0	28.0	31.0	30.5	31.0	30.5	31.0	31.0	30.0	31.0	30.0	31.0
4.0	31.0	28.0	31.0	30.5	31.0	30.5	31.0	31.0	30.0	31.0	30.0	31.0
5.0	31.0	28.0	31.0	30.5	31.0	30.5	30.5	31.0	29.5	31.0	30.0	31.0
6.0	31.0	28.0	31.0	30.5	31.0	30.5	30.5	31.0	29.5	31.0	30.0	31.0
7.0	31.0	28.0	31.0	30.5	31.0	30.5	30.0	29.5	29.5	30.5	30.0	31.0
8.0	31.0	28.0	30.5	29.5	31.0	29.5	29.5	29.0	29.0	30.5	30.0	31.0
9.0	31.0	28.0	30.5	29.5	30.5	29.5	27.5	27.5	28.5	30.5	30.0	31.0
10.0	31.0	28.0	30.5	28.5	30.5	28.5	25.5	26.0	27.0	30.5	29.5	31.0
11.0	30.5	27.0	30.5	28.0	30.0	28.0	23.5	23.5	25.5	30.5	29.5	31.0
12.0	29.5	26.0	30.5	27.0	29.0	28.0	22.5	20.0	23.0	30.5	28.5	30.5
13.0	26.5	26.0	30.5	27.0	28.5	27.5	18.0	19.5	22.5	30.0	28.5	30.5
14.0	20.5	25.5	30.5	26.0	26.0	21.0	15.0	16.0	19.5	28.0	28.0	28.5
15.0	14.5	24.5	30.5	25.5	26.5	18.5	13.5	14.5	17.0	26.5	27.0	24.5
16.0	9.0	22.5	30.5	25.0	23.5	13.0	11.5	11.5	14.5	24.5	26.0	18.5
17.0	7.0	20.5	28.8	24.0	22.0	9.0	8.5	9.5	12.0	22.5	20.5	11.0
18.0	3.0	15.0	27.5	21.5	20.5	5.0	3.5	5.0	10.0	18.0	15.5	5.0
19.0	1.5	11.5	24.0	20.5	17.0	3.5	3.0	2.0	8.0	11.5	9.5	1.5
20.0	0.0	6.5	19.0	18.0	13.0	1.0	0.5	2.0	6.0	7.0	5.5	0.0
21.0		2.5	14.5	13.5	9.0	0.0	0.5	1.5	3.0	4.0	3.0	
22.0		2.5	5.5	9.0	5.5		0.0	0.5	1.0	1.0	0.5	
23.0		0.5	2.0	5.0	4.5			0.0	0.0	0.5	0.0	
24.0		0.5	0.5	0.5	2.0					0.5		
25.0		0.0	0.0	0.0	0.5					0.0		
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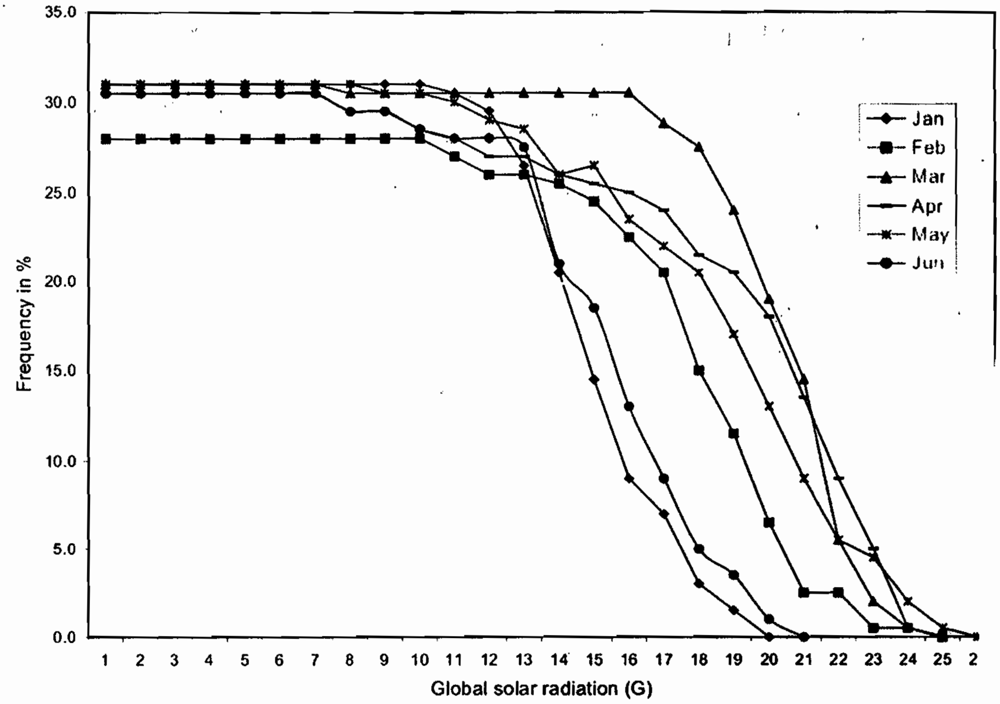

Fig. 3: Cumulative frequency distribution of global solar radiation in % from Jan – Jun

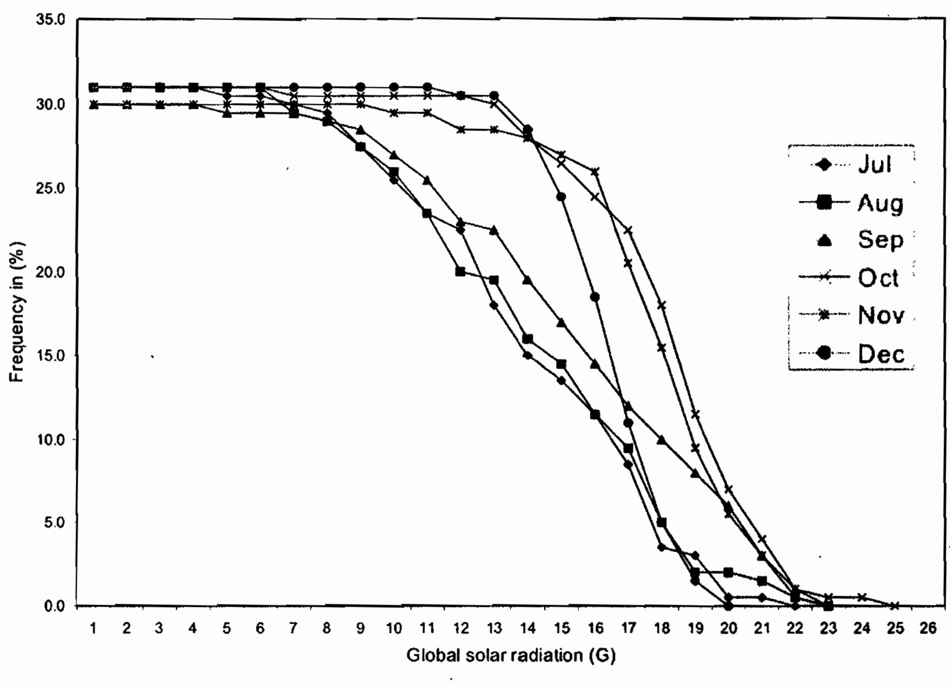

Fig. 4: Cumulative frequency distribution of global solar radiation in % from Jul – Dec

Table 3: Maximum number of consecutive days with insolation above a given threshold.

G	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max. D
1.0	31	30	31	30	31	31	30	31	30	31	31
2.0	31	30	31	30	31	31	30	31	30	31	31
3.0	31	30	31	30	31	31	30	31	30	31	31
4.0	31	30	31	30	31	31	30	31	30	31	31
5.0	31	30	31	30	31	31	30	31	30	31	31
6.0	31	30	31	30	31	31	30	31	30	31	31
7.0	31	30	31	30	31	30	30	31	30	31	31
8.0	31	30	31	30	31	30	30	31	30	31	31
9.0	31	30	31	30	30	28	29	31	30	31	31
10.0	31	29	31	29	28	25	27	31	30	31	31
11.0	31	28	31	29	26	26	26	31	30	31	31
12.0	31	27	30	29	25	24	24	31	29	31	31
13.0	31	27	29	28	18	21	23	31	29	31	31
14.0	31	27	28	25	16	18	21	29	28	30	31
15.0	31	27	27	23	14	15	20	27	27	27	31
16.0	31	27	25	22	13	13	18	25	26	21	31
17.0	28	27	24	19	10	12	16	24	23	16	28
18.0	28	24	21	15	5	8	13	18	16	10	28
19.0	26	23	18	10	5	3	11	12	10	3	26
20.0	22	22	14	6	1	3	7	9	6	0	22
21.0	17	16	10	4	1	2	4	4	4		17
22.0	7	10	7	1	0	1	1	4	1		10
23.0	4	6	6	0		0	0	2	0		6
24.0	1	1	3					0			3
25.0	0	1	1								1
26.0		0	0								0
27.0											
28.0											
29.0											
30.0											
31.0											
32.0											
33.0											
34.0											

Table 4: Consecutive number of days in the year with selected threshold values.

Threshold radiation (G)	First day	Last day	No. of consecutive days
5	0	365	365
10	0	365	365
15	5	361	356
20	28	344	306
25	119	244	105

3. There are also double minima of 1.93 MJm^{-2} (primary) in August and 2.50 MJm^{-2} (Sunday) in January both again occurring at 13.00 hours (LST).
4. Afternoon values are generally higher than those occurring before noon.
5. Maximum insolation is obtained between 10.00 15.00 hours (LST). In terms of percentage the peak varies between 63.4% in August and 70.8% in December.
6. Monthly average daily totals lie between 20.92 MJm^{-2} in March and 13.71 MJm^{-2} in August - a factor of 1.5.
7. For cumulative frequency distribution, the number of days above defined threshold values is reported in Table 2.
8. The maximum/consecutive number of days of insolation above defined threshold values is also reported in Table 5 and Table 6 which provides solar utilization season lengths above selected energy levels during the year cycle.
9. Solar utilization season length covers 365 days of the year for energy levels as high as 10-15MJm^{-2} per day.
10. Periods of low radiation normally below 8.38 MJm^{-2} do not exist in Ilorin implying that the problem of storage and 'back-up' facing Engineers when considering practical application is not expected in this part of the world. From the results presented, it can be seen that global solar radiation in Ilorin shows high relative efficiency for solar utilization.

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