ESTIMATION OF DIRECT SOLAR RADIATION INTENSITIES

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ABSTRACT

This paper estimates the hourly direct solar radiation intensity available on clear days at any given location. Test cases have been produced for various locations in Nigeria such as Calabar, Lagos, Enugu, Benin, Akure, Ado - Ekiti, Jos and Maiduguri. The computation is based upon some empirical formula which considers the passage of the sun's radiation through the atmosphere, and this radiation is attenuated in proportion to the length of path according to an extinction coefficient to produce the direct normal radiation at the earth surface. A computer programme was written for this empirical formula to estimate the solar radiation intensities at some various locations on earth on hourly basis for the 15th day of every month of the year.

Test cases showed that solar radiation intensities increased from 7.00 a.m. solar hour through 12.00 noon solar hour. For example, Akure, on latitude 7.25 deg. North had highest radiations in the month of August through March; values ranging from 904.36 Watts per square meter to 1012.42 Watts per square Meter for the 12.00 solar hour have been recorded. These values thereafter decreased in the months of April through July, reaching between 948.70W/m^2 and 876.47 W/m^2 for the same time period. (See Table 5)

1. INTRODUCTION

The performance of any solar thermal system will depend upon the amount of solar radiation available to such system. This varies with the day of the year due to the variations in the earth-sun distance. On daily basis, it reaches a maximum at noon when the sun is overhead and the path length through the atmosphere is shortest. The daylight hours also vary seasonally, this is shortest during the hamattan months.

As the solar beam passes through the atmosphere, it is attenuated largely by the atmospheric constituents notably air molecules, dust particles, water vapour molecules and ozone. The solar intensity received at the ground level is the residual intensity after absorption and scattering processes in the atmosphere. A portion of the scattered radiation reaches the earth in a diffuse form. A surface on earth may be irradiated by three types of solar intensities viz : direct solar radiation, diffuse solar radiation from the sky vault and the solar radiation reflected upon the earth surface by adjacent ground and nearby objects.

1. DIRECT SOLAR RADIATION INTENSITIES ON CLEAR DAYS

The availability of solar energy at the earth's surface is highly variable from day to day because of the occurrence of clouds.

During clear days the atmosphere may significantly reduce the energy of the sun's rays, during days of heavy cloudiness, practically no solar energy may directly reach the earth's surface. However, atmospheric water vapour and clouds also form a barrier to loss of long wavelength radiation from the earth's surface.

The effects of earth's atmosphere upon solar radiation have been studied by various scientists for many years. Researches have shown that when solar radiation passes through the atmosphere, part of it may be intercepted by constituents such as dry air molecules, water molecules and dust particles resulting in scattering of radiation in all directions.

Secondly, part of the radiation may be absorbed, particularly by ozone in the upper atmosphere and by water vapour near the earth's surface. The remaining portion of the original direct radiation quantity may reach the earth surface unchanged in wavelengths.

A lot of studies have been carried out by many investigators on the mechanism of scattering and absorption by atmospheric constituents. Fritzs (1957) summarized the available materials and presented a procedure for calculating these scattering effects. Experimental observations have shown that for monochromatic radiation, the quality of radiation depleted by absorption and scattering increases arithmetically with the intensity of radiation and geometrically with the material passed through the sun's rays. Thus

$$In, \lambda = Ino, \lambda * T_{\lambda}$$

Where: In, λ = the monochromatic intensity normal to the sun's rays after passage through m units of material.

Ino, λ = the initial monochromatic intensity

$T \lambda$ = monochromatic transmissivity for unit depth of material.

In solar radiation calculations, unit depth of atmosphere is taken as the depth when the sun is at its zenith. The air mass (m) is the ratio of the length of path of the sun's rays through the atmosphere to the length of path if the sun were at the zenith. Except for very low solar altitude angles, the air mass is equal to the cosecant of the altitude angle. Parry Moon (1940) correlated the work of several investigators and calculated overall transmissivities for monochromatic radiation including the effects of scattering by dry air molecules, water vapour molecules and dust particles and the effect of absorption by ozone and water vapour. At any wavelength, the overall transmissivity multiplied by the intensity at the outer limit of atmosphere gives the intensity at the earth's surface. Such calculations carried out for the earth's solar spectrum allow energy distribution curves to be drawn for a location at the earth's surface for any point within the atmosphere.

2. ESTIMATION OF DIRECT SOLAR RADIATION AVAILABLE ON CLEAR DAYS FOR A GIVEN LOCATION

The intensity of direct solar radiation available on clear days can be estimated for a given area or location if certain pararameters can be determined. Several approaches have been developed, Heywood (1966) for example has made extensive simultaneous measurements area of total radiation on horizontal and inclined planes under cloudless sky conditions in London area. In this present work , an analytical method using empirical equations developed into computer programme will be utilized for this estimation

2.1 LITERATURE REVIEW

Threlkeld and Jordan (1957) analysed a procedure for estimating the direct solar radiation intensity available on clear days for a particular location of know latitude. The procedure entailed that a basic atmosphere be defined or determined based upon the following parameters: latitude of the location; the clearness number; the amount of atmospheric dust particles per cc; the depth of atmospheric precipitable water in cm; the depth of ozone in atmosphere; and the elevation in meters. Calculations were made for each hour angle from 6.00 a.m. - 6.00 p.m. based upon the appropriate transmission factors for the basic atmosphere. These transmission factors which had been made into curves were functions of the air mass (m). The air mass was calculated as the cosecant of the altitude angle β, and β can be calculated from the expression:

$$\text{Sin } \beta = \cos l \cos d \cos h + \text{Sin } l \text{ Sin } d \quad \ldots (2)$$

Where: β = altitude angle

l = latitude

d = declination

h = hour angle

$$\text{air mass (m)} = \text{cosec } \beta \quad \ldots (3)$$

The intensity of direct solar radiation was then calculated thus:

$$IDN = T * SC * Io/Isc \quad \ldots (4)$$

Where :

IDN = intensity of direct solar radiation (W/m2)

T = Transmission factor

SC = Solar Constant

Io/Isc = Ratio of solar radiation at outer limit of atmosphere to solar constant.

2.2 ANALYTICAL METHOD OF ESTIMATING DIRECT SOLAR RADIATION

This present work of estimating the intensity of direct solar radiation uses a different approach, and is purely analytical with the use of some empirical equations programmed into the computer to give the hourly direct insolation on clear days.

2.2.1 FUNDAMENTAL PARAMETERS

(I) EXTRATERRESTRAL RADIATION

The extraterrestrial solar intensity at the mean distance from the earth to the sun line but at the outer limit of the atmosphere is called the solar constant, Isc. Johnson (1954) determined the solar constant to be 1353 W/m2 with a probable error of plus or minus two percent.

The apparent extraterrestrial solar radiation Io, varies over the year as the earth -sun distance changes seasonally, being a bit higher than solar constant, Isc in January and equally lower in June. Table 1 gives the monthly values of the extraterrestrial radiation Io in W/m2 and the earth - sun distance in km. The average earth sun - sun distance is 1.49 * E+08 km. Values of Io can be approximated by the empirical formula:

$$Io = Isc(1 + 0.033 \cos(360*N/370)) \quad \text{..... (5)}$$

where N is the day number in the year e.g Jan. 17, N=17 and on March 21, N=80.

TABLE 1 EXTRATERRESTRAL RADIATION **

Date	Io, W/m2	E S D * 1.E+08	E = Earth S = Sun D = Distance
Jan 1	1399	1.471	
Feb 1	1394	1.474	
Mar 1	1378	1.482	
Apr 4a	1353	1.496	mean ESD, Io = Isc
May 1	1333	1.507	
Jun 1	1316	1.517	
Jul 1	1309	1.521	
Aug 1	1313	1.519	
Sep 1	1328	1.510	
Oct 5a	1353	1.496	mean ESD, Io = ISc
Nov 1	1373	1.485	
Dec 1	1392	1.475	

E S D = Earth - Sun Distance in 1.0E+08 KM

** Source : Solar Thermal Engineering, Peter J. Lunde

(II) DECLINATION ANGLE

The changes in the apparent exterterrestral radiation through the months of the year is caused by the seasonally changing path of the sun through the sky. Changes in the sun's azimuth and altitude angles relative to the earth and changes in the length of time the sun spends above the horizon have a significant effect on the total radiation received on the earth.

The seasonal change in the sun's path through the sky is due to the inclination of the earth's axis of daily rotation at 23.45 degrees to perhaps a more logical axis perpendicular to the plane of the earth's orbit around the sun. Because of this, all regions, especially the area nearest to the poles receive more light in summer and less light in winter than would otherwise be. The angle that the sun rays make with the equitorial plane at solar noon is called the angle of declination, (d). The angle of declination varies from +23.45 deg. in June to -23.45 deg. in December. The following empirical equation is used for calculating the declination angle, d:

$$d = 23.45 \text{ Din } ((N+80) *360/370) \quad \text{---------- (6)}$$

where N is the day number of the year.

2.2.2 CLEAR SKY IRRADIATION

As the sun's radiation passes through the atmosphere, it is attenuated in proportion to the length of its path according to an extinction coefficient, PB, to produce the direct normal irradiation at the earth's surface. Thus:

$$IDN = PA * \exp(-p/po * PB/ \cos \theta z) \quad \text{----- (7)}$$

where :

IDN = direct normal irradiation W/m²

PA = terrestral solar radiation on the earth's surface, W/m²

PB = the extinction coefficient

θz = zenith angle

p/po = pressure at the location concerned relative to the standard atmosphere and is give as:

p/po = Exp (-0.0001184 * altitude in meters above sea level

Cos θz = Cos 1 Cos d Cos h + Sin 1 Sin d -------- (8)

Peter J. Lunde (1980) gave the monthly values for the apparent extraterrestral solar intensity PA and the extinction coefficient PB and these are shown in Table 2. The PA values are derived from equation (5). The zenith angle term accounts for the longer path length through the atmosphere when the sun is perpendicular to the earth surface. IDN, the direct normal irradiance is the energy of the direct solar beam falling on a unit area perpendicular to the beam at the earth's surface.

TABLE 2 PARAMETERS (A & B) USED IN SOLAR RADIATION CALCULATIONS

Date Month	Parameter PA W/m²	Parameter PB Dimesionless
Jan 15	1230	.142
Feb 15	1215	.144
Mar 15	1186	.156
Apr 15	1136	.180
May 15	1104	.196
Jun 15	1088	.205
Jul 15	1085	.207
Aug 15	1107	.201
Sep 15	1151	.177
Oct 15	1192	.160
Nov 15	1221	.149
Dec 15	1233	.142

2.3 COMPUTER PROGRAMME FOR ESTIMATION OF DIRECT SOLAR RADIATION ON CLEAR DAYS FOR ANY GIVEN LOCATION

A Computer programme has been developed to determine the hourly direct solar radiation intensity at any given location with known latitude. The calculation is based on Equation (7) previously discussed. The programme takes into consideration the latitude (LAT) of the location in question, (positive for the Northern hemisphere and negative for the South); the day of the month (date) which determines the declination angle (d) using Equation (6) ; and the hour angle (HR) for the respective hours for calculating the zenith angle (θz) from Equation (8). The values of parameters PA and PB, the extraterrestral solar radiation, and the extinction coefficient respectively are given in Table 2. The PA values are some average values for the individual months as given by Peter J. Lunde (1980).

2.3.1 COMPUTATIONAL ANALYSIS

The programme will run for each solar hour (say from 7.00 hr to 17.00 hr) of a specific day (DN) of a particular month (MO) e.g January 15 and for a given location of know latitude; say Akure, Ondo State, latitude 7.25 deg. North as given by Encyclopedia Britannica (1967). Consider a sample computation for a particular solar hour, say 9.0 hr, the hour angle is calculated as (12-9)*15 deg. Thus the hour angle for 9.00 hr is 45 deg.

(i) Calculate the declination angle d using Equation (6) for Jan 15 day number N = 15

d = 23.45*sin ((15-80) *360/356)

d = - 21.1 degrees

(ii) Calculate the zenith angle 0z using equation (8)

Cos 0z = Cos 1 Cos d Cos h + Sin 1 Sin d

Cos (7.25)*Cos (-21.1)*Cos (45) + Sin (7.25) *Sin (-21.1)

Cos 0z = 0.60896

(iii) Calculate the direct solar radiation from Equation (7)

Idn = PA*exp (-p/po * PB/cos 0z)

p/po = 1, since computation is for sea level

Using parameters PA and PB from Table 2.

A = 1230 W/m2 and B = 0.142

Therefore:

Idn = 1230 * exp (- 0.142/0.60896)

Idn = 974.19 W/m2 for 9.00 solar hour.

This calculation goes on for all the other hours, but it should however be noted that the intensity of radiation reaching the earth surface is symmetrical about the solar noon, thus the solar hours of 9.00 and

15.00, 11.00 and 13.00; 10.00 and 14.00; etc may experience the same radiation as these hours have the same hour angle from the solar noon.

2.4 TEST CASES AND RESULTS

This programme has been run and tested for several cities in Nigeria. Test cases printed out for this work are for the following cities : Calabar, Lagos, Akure, Ilorin, Jos, Maiduguri, Sokoto and Ado-Ekiti; Table3,4,5,6,7,8,9,10 respectively. However, Benin and Enugu have the same latitude as Lagos hence the values obtained for Lagos (Table 4) are also applicable to these locations.

A typical result for a location, say Maiduguri, latitude12 degree North, shows that for every month of the year, assuming clear days, solar radiation intensity increases from 7.00a.m. solar time through 12 noon solar time. It can be seen that the solar radiation intensities are highest in the month of August through March, values increasing from 905.37 Watts/m2 to 1009 Watts/m3, thereafter it starts to fall. This same trend is true for other locations.

Figures 1 and 2 show the curves for the hourly radiation intensities for the 15th day of the month throughout the year for two of the test locations " Fig 1 for Akure and Fig 2 for Maiduguri. The curves are in agreement with the calculated results printed out in the tables.

Duffie and Beckman (1980) produced tables of monthly average daily solar radiation intensity on horizontal surfaces for several cities in United States and Toyko, Preritoria, Stockholm etc. The table showed the monthly radiation from January through December.

2.5 CONCLUSION

The analysis thus presented has been the estimation of solar radiation intensities reaching the earth surface on clear days in any location with know latitude. Some empirical formula developed into computer programme gave the results printed out for several locations in Nigeria such as Calabar, Lagos, Akure, Jos etc. The highest radiation estimated was 1050.11 W/m2 on January 15 at 12 solar noon at Calabar test case, latitude 5 deg. North, and the lowest radiation from this station was 506.71 W/m2. Values for other locations can easily be read from their Tables.

REFERENCES

1. Britannica, (1967), Encyclopaedia Britannica; Britannica World Atlas International; William Benton Publisher.

2. **DUFFIE J. A. AND BECKMAN W. A**, (1980); Available Solar Radiation; Solar Engineering of Thermal Processes, Wiley Interscience Inc. Ch. 2, p 44.

3. **FRITZ, S** (1957), Solar Energy on clear days; The Scientific Monthly Journal Vol. 84, Feb. 1957, pp 55-56

4. **HEYWOOD, H** (1966), The computation of solar radiation intensities; Solar Energy Vol. 10, 1966, p 51

5 **JOHNSON, F. S.** (1954), The Solar constant; Journal of Metreology, Vol 11, Dec 1954, pp 431 - 439

6. **LUNDE, P. J.** (1980), Extraterrestral Radiation, Solar Thermal Engineering; John Wiley and Sons Inc., NY, Ch. 3, pp 64-65.

7. **MOON, P,** (1940) Proposed standard solar radiation curves for engineering use, Journal of the Franklin Institute, Vol. 230, Nov. 1940, pp 583 - 617.

8. **THRELKELD, J. L. AND JORDAN R. C,** (1957), Direct solar radiation available on clear days; ASHRAE Journal, Heating, Piping and Airconditioning Section, Dec. 1957, pp 135 - 145.

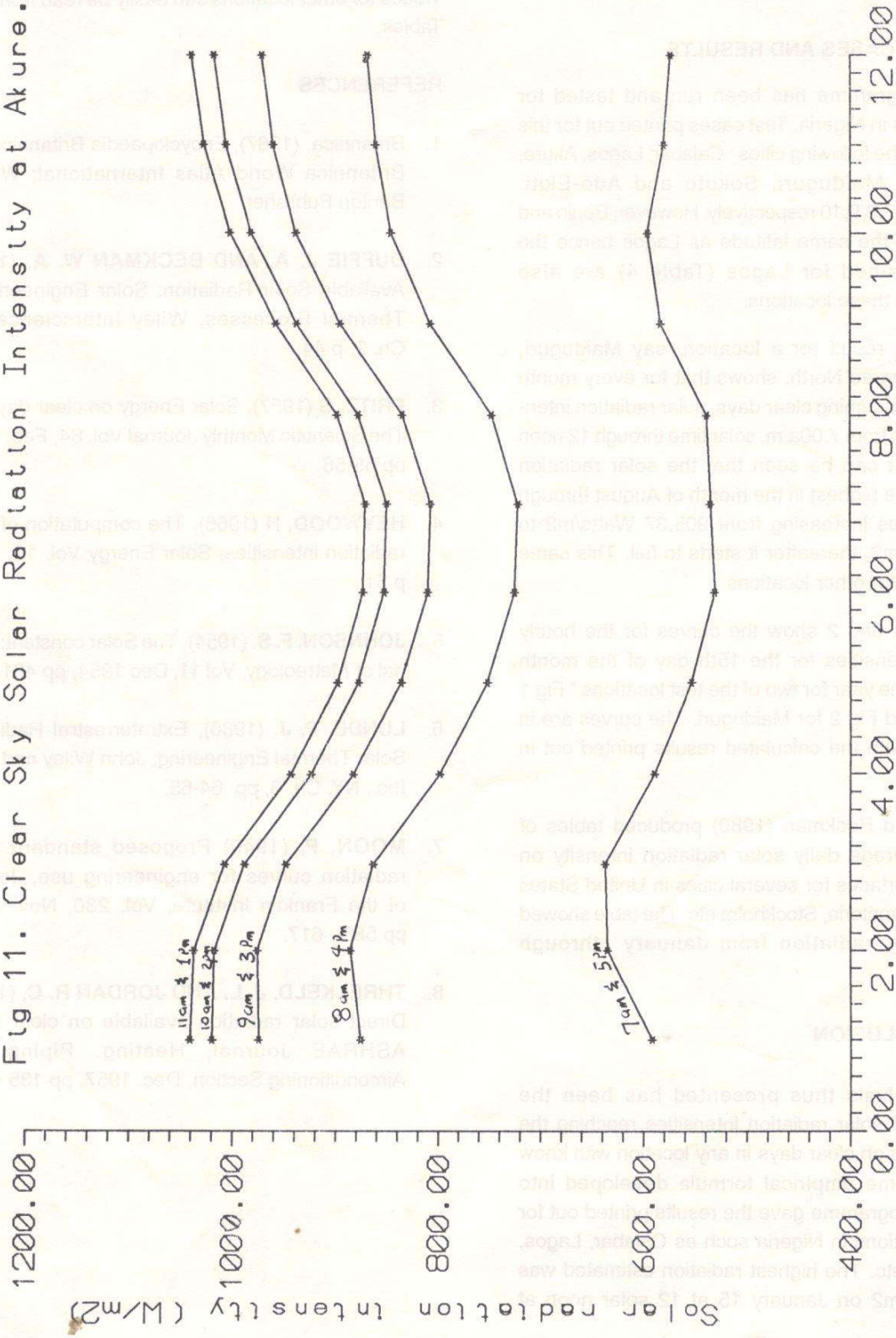


Fig 11. Clear Sky Solar Radiation Intensity at Akure.

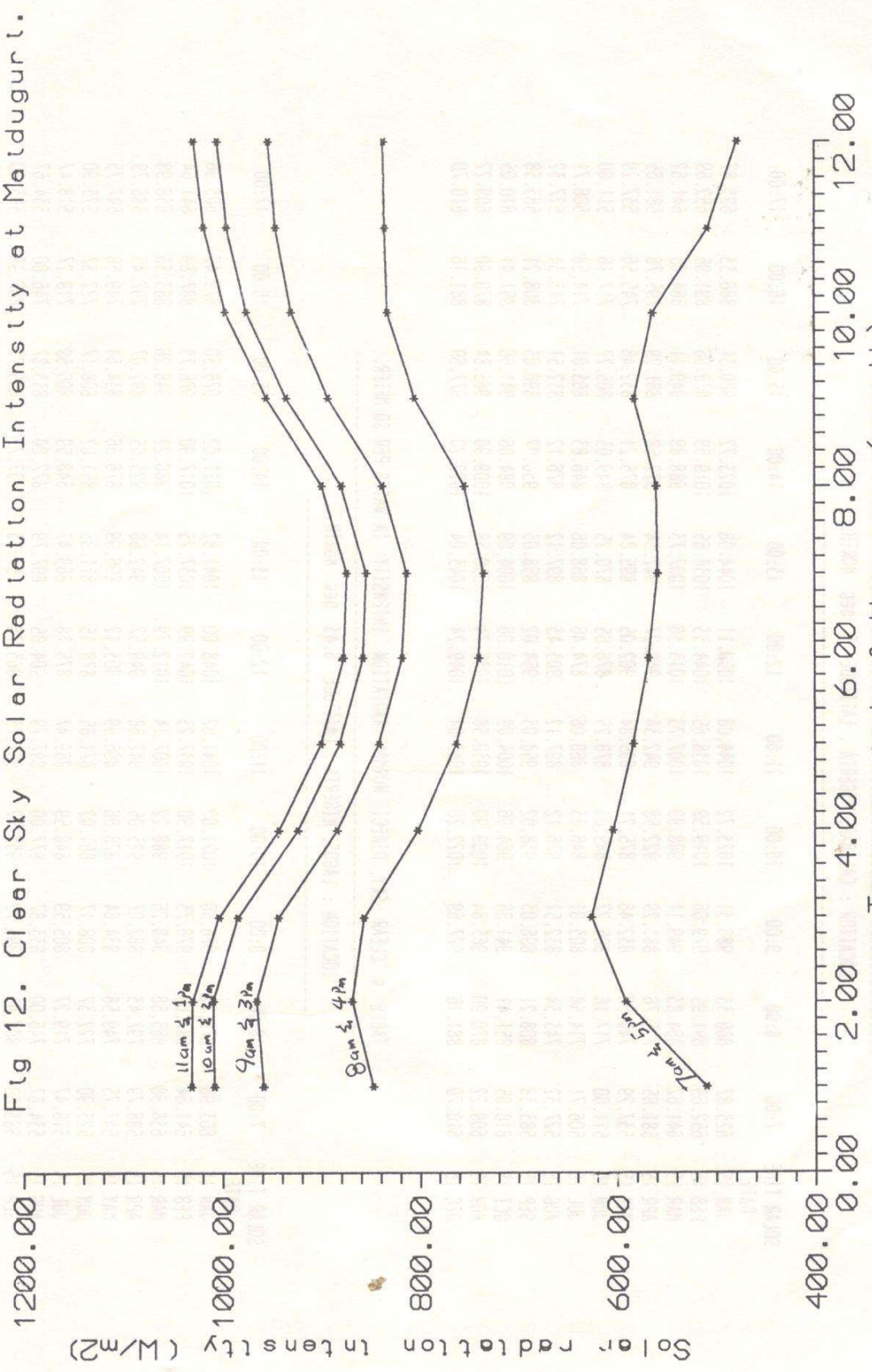

Fig 12. Clear Sky Solar Radiation Intensity at Maiduguri.
Solar radiation intensity (W/m2)
1200.00
1000.00
800.00
600.00
400.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
Time period of the year (month)
11am & 1pm
10am & 2pm
9am & 3pm
8am & 4pm
7am & 5pm

TABLE 3 CLEAR SKY, DIRECT NORMAL RADIATION INTENSITY IN WATTS PER SQ METER.

LOCATION : CALABAR, NIGERIA . LATITUDE 5 DEG NORTH

SOLAR TIME DATE	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
JAN 15	623.87	886.33	980.31	1023.72	1044.06	1050.11	1044.06	1023.72	980.31	886.33	623.87
FEB 15	652.69	891.95	979.06	1019.59	1038.65	1044.33	1038.65	1019.59	979.06	891.95	652.69
MAR 15	641.62	864.83	949.11	988.89	1007.73	1013.36	1007.73	988.89	949.11	864.83	641.62
APR 15	581.65	795.76	881.29	922.58	942.34	948.27	942.34	922.58	881.29	795.76	581.65
MAY 15	537.29	745.56	832.48	875.21	895.84	902.05	895.84	875.21	832.48	745.56	537.29
JUN 15	511.00	717.16	805.27	849.03	870.25	876.65	870.25	849.03	805.27	717.16	511.00
JUL 15	506.71	714.58	803.01	846.83	868.06	874.46	868.06	846.83	803.01	714.58	506.71
AUG 15	527.32	743.34	832.51	876.12	897.12	903.43	897.12	876.12	832.51	743.34	527.32
SEP 15	583.38	808.21	896.03	938.02	958.03	964.02	958.03	938.02	896.03	808.21	583.38
OCT 15	610.05	851.41	941.66	984.06	1004.09	1010.06	1004.09	984.06	941.66	851.41	610.05
NOV 15	609.22	870.90	965.84	1009.90	1030.58	1036.74	1030.58	1009.90	965.84	870.90	609.22
DEC 15	610.70	881.16	977.69	1022.20	1043.04	1049.24	1043.04	1022.20	977.69	881.16	610.70

TABLE 4 CLEAR SKY, DIRECT NORMAL RADIATION INTENSITY IN WATTS PER SQ METER.

LOCATION : LAGOS, NIGERIA . LATITUDE 6.43 DEG NORTH

SOLAR TIME DATE	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
JAN 15	603.96	879.42	976.50	1021.02	1041.82	1048.00	1041.82	1021.02	976.50	879.42	603.96
FEB 15	641.64	887.89	976.73	1017.90	1037.23	1042.99	1037.23	1017.90	976.73	887.89	641.64
MAR 15	638.98	863.56	948.26	988.22	1007.14	1012.79	1007.14	988.22	948.26	863.56	638.98
APR 15	586.79	797.43	882.07	923.05	942.68	948.57	942.68	923.05	882.07	797.43	586.79
MAY 15	547.75	749.58	834.64	876.66	896.99	903.12	896.99	876.66	834.64	749.58	547.75
JUN 15	523.90	722.37	808.17	851.02	871.85	878.15	871.85	851.02	808.17	722.37	523.90
JUL 15	518.47	719.27	805.59	848.59	869.47	875.78	869.47	848.59	805.59	719.27	518.47
AUG 15	534.67	746.00	833.87	877.00	897.79	904.05	897.79	877.00	833.87	746.00	534.67
SEP 15	583.60	807.95	895.72	937.72	957.73	963.73	957.73	937.72	895.72	807.95	583.60
OCT 15	601.50	848.05	939.67	982.60	1002.85	1008.89	1002.85	982.60	939.67	848.05	601.50
NOV 15	591.25	864.51	962.27	1007.36	1028.47	1034.75	1028.47	1007.36	962.27	864.51	591.25
DEC 15	587.76	873.29	973.37	1019.17	1040.53	1046.87	1040.53	1019.17	973.37	873.29	587.76

TABLE 5 CLEAR SKY, DIRECT NORMAL RADIATION INTENSITY IN WATTS PER SQ METER.

LOCATION : AKURE, NIGERIA . LATITUDE 7.25 DEG NORTH

SOLAR TIME DATE	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
JAN 15	591.85	875.26	974.19	1019.39	1040.47	1046.73	1040.47	1019.39	974.19	875.26	591.85
FEB 15	635.00	885.43	975.31	1016.88	1036.37	1042.17	1036.37	1016.88	975.31	885.43	635.00
MAR 15	637.35	862.75	947.71	987.78	1006.75	1012.42	1006.75	987.78	947.71	862.75	637.35
APR 15	589.60	798.30	882.45	923.26	942.82	948.70	942.82	923.26	882.45	798.30	589.60
MAY 15	553.48	751.76	835.80	877.43	897.60	903.68	897.60	877.43	835.80	751.76	553.48
JUN 15	530.95	725.22	809.74	852.08	872.71	878.95	872.71	852.08	809.74	725.22	530.95
JUL 15	524.90	721.82	806.98	849.52	870.22	876.47	870.22	849.52	806.98	721.82	524.90
AUG 15	538.70	747.43	834.58	877.44	898.13	904.36	898.13	877.44	834.58	747.43	538.70
SEP 15	583.61	807.72	895.48	937.49	957.51	963.51	957.51	937.49	895.48	807.72	583.61
OCT 15	596.37	846.02	938.46	981.70	1002.08	1008.16	1002.08	981.70	938.46	846.02	596.37
NOV 15	580.37	860.65	960.10	1005.82	1027.19	1033.54	1027.19	1005.82	960.10	860.65	580.37
DEC 15	573.76	868.53	970.76	1017.33	1039.01	1045.44	1039.01	1017.33	970.76	868.53	573.76

TABLE 6 CLEAR SKY, DIRECT NORMAL RADIATION INTENSITY IN WATTS PER SQ METER.

LOCATION : ILORIN, NIGERIA . LATITUDE 8.5 DEG NORTH

SOLAR TIME DATE	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
JAN 15	572.36	868.59	970.50	1016.78	1038.30	1044.68	1038.30	1016.78	970.50	868.59	572.36
FEB 15	624.43	881.51	973.03	1015.21	1034.96	1040.83	1034.96	1015.21	973.03	881.51	624.43
MAR 15	634.68	861.40	946.78	987.04	1006.09	1011.78	1006.09	987.04	946.78	861.40	634.68
APR 15	593.67	799.51	882.95	923.50	942.97	948.82	942.97	923.50	882.95	799.51	593.67
MAY 15	561.86	754.92	837.46	878.51	898.44	904.46	898.44	878.51	837.46	754.92	561.86
JUN 15	541.24	729.36	812.00	853.61	873.93	880.08	873.93	853.61	812.00	729.36	541.24
JUL 15	534.31	725.54	808.99	850.86	871.27	877.45	871.27	850.86	808.99	725.54	534.31
AUG 15	544.58	749.47	835.57	878.03	898.56	904.75	898.56	878.03	835.57	749.47	544.58
SEP 15	583.47	807.25	895.02	937.07	957.11	963.12	957.11	937.07	895.02	807.25	583.47
OCT 15	588.21	842.75	936.49	980.23	1000.83	1006.97	1000.83	980.23	936.49	842.75	588.21
NOV 15	562.92	854.48	956.65	1003.35	1025.13	1031.60	1025.13	1003.35	956.65	854.48	562.92
DEC 15	551.11	860.91	966.59	1014.39	1036.57	1043.15	1036.57	1014.39	966.59	860.91	551.11

TABLE 7 CLEAR SKY, DIRECT NORMAL RADIATION INTENSITY IN WATTS PER SQ METER.

LOCATION : JOS, NIGERIA . LATITUDE 9.91 DEG NORTH

SOLAR TIME DATE	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
JAN 15	548.73	860.58	966.08	1013.64	1035.68	1042.21	1035.68	1013.64	966.08	860.58	548.73
FEB 15	611.81	876.80	970.28	1013.20	1033.25	1039.21	1033.25	1013.20	970.28	876.80	611.81
MAR 15	631.42	859.70	945.60	986.09	1005.24	1010.96	1005.24	986.09	945.60	859.70	631.42
APR 15	597.97	800.71	883.38	923.67	943.04	948.87	943.04	923.67	883.38	800.71	597.97
MAY 15	570.82	758.26	839.17	879.61	899.28	905.23	899.28	879.61	839.17	758.26	570.82
JUN 15	552.22	733.76	814.38	855.19	875.17	881.23	875.17	855.19	814.38	733.76	552.22
JUL 15	544.36	729.47	811.08	852.23	872.34	878.43	872.34	852.23	811.08	729.47	544.36
AUG 15	550.87	751.58	836.53	878.58	898.94	905.08	898.94	878.58	836.53	751.58	550.87
SEP 15	583.10	806.56	894.38	936.48	956.55	962.57	956.55	936.48	894.38	806.56	583.10
OCT 15	578.52	838.81	934.10	978.45	999.30	1005.51	999.30	978.45	934.10	838.81	578.52
NOV 15	541.88	847.10	952.50	1000.39	1022.65	1029.25	1022.65	1000.39	952.50	847.10	541.88
DEC 15	523.53	851.74	961.58	1010.86	1033.64	1040.38	1033.64	1010.86	961.58	851.74	523.53

TABLE 8 CLEAR SKY, DIRECT NORMAL RADIATION INTENSITY IN WATTS PER SQ METER.

LOCATION : MAIDUGURI, NIGERIA . LATITUDE 12 DEG NORTH

SOLAR TIME DATE	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
JAN 15	510.18	847.69	958.96	1008.59	1031.46	1038.23	1031.46	1008.59	958.96	847.69	510.18
FEB 15	591.64	869.25	965.84	1009.92	1030.47	1036.57	1030.47	1009.92	965.84	869.25	591.64
MAR 15	626.05	856.84	943.59	984.46	1003.79	1009.56	1003.79	984.46	943.59	856.84	626.05
APR 15	603.82	802.15	883.77	923.71	942.95	948.74	942.95	923.71	883.77	802.15	603.82
MAY 15	583.19	762.79	841.42	880.99	900.31	906.15	900.31	880.99	841.42	762.79	583.19
JUN 15	567.35	739.77	817.58	857.27	876.79	882.72	876.79	857.27	817.58	739.77	567.35
JUL 15	558.24	734.84	813.86	854.00	873.70	879.67	873.70	854.00	813.86	734.84	558.24
AUG 15	559.54	754.34	837.69	879.16	899.29	905.37	899.29	879.16	837.69	754.34	559.54
SEP 15	582.09	805.21	893.16	935.37	955.52	961.56	955.52	935.37	893.16	805.21	582.09
OCT 15	563.12	832.48	930.22	975.52	996.78	1003.11	996.78	975.52	930.22	832.48	563.12
NOV 15	507.82	835.22	945.83	995.61	1018.64	1025.47	1018.64	995.61	945.83	835.22	507.82
DEC 15	478.19	836.92	953.52	1005.18	1028.93	1035.94	1028.93	1005.18	953.52	836.92	478.19

TABLE 9 CLEAR SKY, DIRECT NORMAL RADIATION INTENSITY IN WATTS PER SQ METER.

LOCATION : SOKOTO, NIGERIA . LATITUDE 13 DEG NORTH

SOLAR TIME DATE	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
JAN 15	490.09	841.05	955.30	1005.99	1029.29	1036.18	1029.29	1005.99	955.30	841.05	490.09
FEB 15	581.33	865.37	963.55	1008.23	1029.03	1035.20	1029.03	1008.23	963.55	865.37	581.33
MAR 15	623.26	855.32	942.51	983.58	1003.00	1008.80	1003.00	983.58	942.51	855.32	623.26
APR 15	606.39	802.71	883.85	923.64	942.82	948.60	942.82	923.64	883.85	802.71	606.39
MAY 15	588.75	764.78	842.38	881.55	900.71	906.51	900.71	881.55	842.38	764.78	588.75
JUN 15	574.14	742.45	818.97	858.16	877.47	883.33	877.47	858.16	818.97	742.45	574.14
JUL 15	564.47	737.22	815.06	854.75	874.25	880.17	874.25	854.75	815.06	737.22	564.47
AUG 15	563.42	755.51	838.13	879.34	899.37	905.42	899.37	879.34	838.13	755.51	563.42
SEP 15	581.42	804.43	892.47	934.75	954.93	960.99	954.93	934.75	892.47	804.43	581.42
OCT 15	555.28	829.23	928.21	974.00	995.47	1001.86	995.47	974.00	928.21	829.23	555.28
NOV 15	490.18	829.12	942.41	993.15	1016.58	1023.51	1016.58	993.15	942.41	829.12	490.18
DEC 15	454.42	829.26	949.37	1002.26	1026.50	1033.65	1026.50	1002.26	949.37	829.26	454.42

TABLE 10 CLEAR SKY, DIRECT NORMAL RADIATION INTENSITY IN WATTS PER SQ METER.

LOCATION : ADO - EKITI, NIGERIA . LATITUDE 7.5 DEG NORTH

SOLAR TIME DATE	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
JAN 15	588.06	873.95	973.47	1018.88	1040.04	1046.33	1040.04	1018.88	973.47	873.95	588.06
FEB 15	632.93	884.67	974.87	1016.55	1036.09	1041.91	1036.09	1016.55	974.87	884.67	632.93
MAR 15	636.83	862.49	947.53	987.64	1006.62	1012.29	1006.62	987.64	947.53	862.49	636.83
APR 15	590.43	798.56	882.56	923.31	942.86	948.73	942.86	923.31	882.56	798.56	590.43
MAY 15	555.19	752.41	836.14	877.66	897.77	903.85	897.77	877.66	836.14	752.41	555.19
JUN 15	533.05	726.06	810.20	852.40	872.96	879.18	872.96	852.40	810.20	726.06	533.05
JUL 15	526.82	722.58	807.40	849.80	870.43	876.67	870.43	849.80	807.40	722.58	526.82
AUG 15	539.90	747.85	834.79	877.57	898.22	904.44	898.22	877.57	834.79	747.85	539.90
SEP 15	583.60	807.63	895.40	937.42	957.44	963.44	957.44	937.42	895.40	807.63	583.60
OCT 15	594.77	845.38	938.07	981.41	1001.84	1007.93	1001.84	981.41	938.07	845.38	594.77
NOV 15	576.96	859.44	959.43	1005.34	1026.79	1033.16	1026.79	1005.34	959.43	859.44	576.96
DEC 15	569.36	867.04	969.95	1016.76	1038.53	1044.99	1038.53	1016.76	969.95	867.04	569.36