FOURIER ANALYSIS OF DAILY SOLAR RADIATION DATA IN EGYPT

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ABSTRACT

The aim of this work has been to obtain a Typical Annual Time function by the application of a calculating procedure based on a Fourier analysis to a daily solar radiation data of 8 stations of different climatic conditions in Egypt.

This function allows to estimate the most probable value of the Global Solar Radiation for every day of the year. The deviation for the annual average, of any year in the period (1981 - 1986), from the annual average obtained by the Typical Annual Time Function is less than 5 %.

KEY WORDS

Solar radiation over Egypt, Fourier analysis

INTRODUCTION

The determination of the Global Solar Radiation (GSR) is very important in different scientific applications. Recently, it has been recognized that the type of statistical information on solar radiation has generally been published in the professional literature is insufficient for sizing and optimizing solar energy systems of very high solar fractions. For example, the kinds of emperical and even analytic design methods that are appropriate for solar energy systems of intermediate solar fractions do not offer adequate accuracy in the optimal sizing of stand-alone photovoltic systems [1]. Therefore, Solar Radiation Data (SRD) should be "time series" analyzed. A statistical meaningful projections of these data into the future will be given by the analysis for a past period of these "time series" [1, 2].

Shaltout [3] calculated the input solar energy for 77 sites in Egypt using the relative humidity and the cloudness observations with deviation about 5% from the observed values.

Mehanna [4] gave a system of simple linear equations to estimate monthly mean value of GSR over Egypt with deviation about 10 % from the observed values.

A method of calculation has been developed by Alberto and Recio [5] to obtain a Typical Annual Time Function using Fourier analysis for Bercelona.

Also, Baldasano Recio et al [6] had been obtained the Typical Annual Time Function by the application of a calculation procedure based on a Fourier analysis to SRD of 21 stations in Spain.

Helwa and the authors [7] determined the GSR for different latitudes in Egypt by using The Fourier analysis of daily SRD for the year 1982.

DATABASE

It is possible to subdivide the climatological regime of Egypt into different regions as Upper Egypt, Western Desert, Middle Egypt, Cairo area, Delta and Suze Canal, Red Sea and Mediterranean Sea [3]. Therefore, we had choiced our available data to cover the most climatological regions. Actually we could not obtain any data for Sinai and the Red Sea regions. The daily SRD, in our study, were obtained from Solar Radiation and Radiation Balance Data [8]. The names and the climatological regions as well as the available years for each station are indicated in table 1.

Table 1 : Names, Climatological region, and years of data for 8 stations

Station	Climatological region	Years	
Aswan	Upper Egypt	1981, 1983 - 1986	5
Kharga	Western Desert	1981 - 1986	6
Asiut	Middle Egypt	1982 - 1986	5
Cairo	Cairo area	1981 - 1986	6
Bahtim	Cairo area	1981 - 1986	6
Tahrir	Delta and Suze Canal	1981 - 1984, 1986	5
Mersa Matrouh	Mediterranean Sea	1982 - 1986	5
Sidi - Barrani	Mediterranean Sea	1985, 1986	2

METHOD OF ANALYSIS

The procedure of Fourier analysis depends on the fitting of a trigonometric function (sine and cosine components). The analysis by this procedure allows to estimate the amplitude and the phase angle for different harmonics, as well as the percentage of representation of each harmonic in the data (annual variance). To obtain a Typical Annual Time Function, as detailed in [5, 7, 9], we had used the following expression :

$$S\ (D,\ r) = SM_T + AM_T\ (r) \cos\ (2\pi\ Dr/N - \theta_T\ (r)) \qquad (1)$$

where S (D,r) is the estimated daily GSR for any harmonic r, (r = 1, 2, ..., N/2 for 1st, 2nd harmonic, ... etc), and for any day D, (D = 1, 2,..., N); N is the total number of days. SM_T is the annual average of the daily GSR, $AM_T(r)$ and $\theta_T(r)$ are the annual amplitude and the phase angle, respectively, corresponding to the specified harmonic r.

Our method of analysis for obtaining the Typical Annual Time Function consists of two stages:

1. The first stage is to obtain the representive equation of each year, for different stations, by applying Fourier analysis to the set of annual series year after year.
2. The second stage is to obtain the representative equation for the average of all the available years, day by day, for each station. The representative equation in this case will be called Typical representative equation or Typical Annual Time Function.

RESULTS AND DISCUSSIONS

The annual variance, has been estimated by the application of Fourier analysis to obtain either the annual representative equation or the Typical representative equation (corresponding to the first harmonic, varies between 73 % and 97 %. The harmonic is the best harmonic describes the Annual Solar Radiation [5, 7, 9]. Accordingly, the first harmonic will be used in this work.

The annual average (SM_T in MJ/m^2), the amplitude (AM_T in MJ/m^2), Phase angle (θ_T in degree) and the percentage of presentation of the Typical representative equation in the measured data variance; % VAR) are given in table 2. The same variables with the percentage deviation of the annual average for the yearly representative equations, of each station, from the corresponding Typical representative equation are given in tables 3-10.

Table 2 : Parameters of the Typical Annual Time Function for analyzed stations.

Station	Year	SM_T	AM_T	θ_T	% VAR
Aswan	5	23.50	6.60	- 0.1984	94.7
Kharga	6	22.88	6.91	- 0.1758	96.1
Asiut	5	21.75	7.90	- 0.1314	95.9
Cairo	6	19.02	8.46	- 0.1043	97.1
Bahtim	6	19.96	8.68	- 0.1043	97.1
Tahrir	5	19.93	8.62	- 0.1261	97.0
M.Matrouh	5	20.58	9.71	- 0.0952	96.4
Sidi-Barrani	2	19.74	9.40	- 0.1221	91.7

Table 3 : Parameters of the yearly representative equation with deviation of annual average from Typical average for Aswan.

Years	SM_T	AM_T	θ_T	% VAR	% Deviation
1981	24.57	6.71	- 0.2254	88.7	4.55
1983	23.53	6.53	- 0.1476	73.0	0.13
1984	23.33	6.83	- 0.1916	86.1	- 0.72
1985	23.13	6.49	- 0.1631	86.2	- 1.57
1986	23.03	6.52	- 0.2715	92.2	- 2.00

Table 4 : **Parameters of the yearly representative equations with deviation of annual average from Typical average for Kharga.**

Years	SM_T	AM_T	θ_T	% VAR	% Deviation
1981	23.84	7.16	- 0.1810	89.0	4.20
1982	22.84	6.84	- 0.1471	84.2	- 0.17
1983	23.13	6.91	- 0.2070	90.5	1.09
1984	22.58	6.58	- 0.2200	87.0	- 1.31
1985	22.70	7.21	- 0.0958	83.7	- 0.79
1986	22.10	6.81	- 0.2171	92.1	- 3.41

Table 5 : **Parameters of the yearly representative equations with deviation of annual average from Typical average for Asiut.**

Years	SM_T	AM_T	θ_T	% VAR	% Deviation
1982	21.65	7.85	- 0.0906	84.3	- 0.46
1983	22.07	7.93	- 0.1366	88.1	1.47
1984	22.20	7.90	- 0.1744	90.4	2.07
1985	21.50	7.96	- 0.0875	83.0	- 1.15
1986	21.31	7.90	- 0.1761	91.2	- 2.02

Table 6 : **Parameters of the yearly representative equations with deviation of annual average from Typical average for Cairo.**

Years	SM_T	AM_T	θ_T	% VAR	% Deviation
1981	19.82	8.50	- 0.0903	87.5	- 4.21
1982	19.10	8.74	- 0.0875	86.4	0.42
1983	18.87	8.59	- 0.0970	85.3	- 0.79
1984	19.16	8.37	- 0.1588	86.5	0.74
1985	18.51	8.35	- 0.0809	82.5	- 2.68
1986	18.62	8.46	- 0.1552	87.0	- 2.10

Table 7 : **Parameters of the yearly representative equations with deviation of annual average from Typical average for Bahtim.**

Years	SM_T	AM_T	θ_T	% VAR	% Deviation
1981	20.93	8.89	- 0.1057	88.3	4.86
1982	19.75	8.77	- 0.0777	86.8	- 1.05
1983	19.79	8.75	- 0.0871	85.8	- 0.85
1984	20.02	8.46	- 0.1579	88.1	0.30
1985	19.25	8.68	- 0.0688	82.5	- 3.56
1986	19.99	8.54	- 0.1389	85.7	0.15

Table 8 : Parameters of the yearly representative equations with deviation of annual average from Typical average for Tahrir.

Years	SM_T	AM_T	θ_T	% VAR	% Deviation
1981	20.71	8.59	- 0.1168	87.2	3.91
1982	19.81	8.65	- 0.1120	87.0	- 0.60
1983	19.88	8.82	- 0.0749	85.9	- 0.25
1984	20.06	8.75	- 0.1584	88.9	0.65
1986	19.16	8.31	- 0.1797	87.5	- 3.86

Table 9 : Parameters of the yearly representative equations with deviation of annual average from Typical average for Mersa Matrouh.

Years	SM_T	AM_T	θ_T	% VAR	% Deviation
1982	20.59	9.96	- 0.0556	84.2	0.05
1983	20.73	9.88	- 0.0733	85.9	0.73
1984	21.23	9.63	- 0.1039	86.9	3.16
1985	20.51	9.82	- 0.0945	83.9	- 0.34
1986	19.81	9.31	- 0.1613	87.0	- 3.74

Table 10 : Parameters of the yearly representative equations with deviation of annual average from Typical average for Sidi Barrani.

Years	SM_T	AM_T	θ_T	% VAR	% Deviation
1985	20.51	9.82	- 0.0945	83.9	- 0.34
1986	19.81	9.31	- 0.1613	87.0	- 3.74

From tables 3-10, it is clear that the percentage deviation of the annual average for the yearly representative equation, from the average of the Typical one, is less than 5 %. Also, the yearly variance for all the stations is less than that of the Typical Annual Time Function (table 2). This indicates that the Typical Annual Time Function obtained by this method of analysis gives a best fitting for the data of a long period. The longer of the period of the data is the better for determining the Typical Annual Time Function with more accuracy.

Figures 1-8 show the daily values of GSR measured during 1986 and the corresponding representative equation for all the analyzed stations. Figures 9-16 show the representative equations for the period from 1981 to 1986 (dashed lines) and the corresponding Typical Annual Time Function (dotted lines) of the different climatological regions.

Figures 13 and 14 show that there is a similarity for the Typical Annual Time Function of Bahtim and Tahrir. Their maximum values are 28.63 MJ/m^2 in 25th of June for Bahtim, 28.54 MJ/m^2 in 24th of June for Tahrir and minimum values are 11.28 MJ/m^2 in 25 th of December for Bahtim, 11.31 MJ/m^2 in 24th of December for Tahrir. Therefore, Tahrir region can be related to the climatological GSR regime of Cairo area.

The remarkable decrease of the amounts of GSR for Cairo (maximum 27.47 MJ/m^2 in 25^{th} of June and minimum 10.61 MJ/m^2 in 25^{th} of December, Lat. 30° 05' N and Long. 31° 17' E, see Figure 12) with respect to Bahtim, Lat. 30° 08' N and 31° 15' E (see Figure 13) could be atributed to the air pollution in Cairo.

It is clear, also, from Figures 9, 10 and 11 that, the Upper Egypt region have the maximum values of GSR (maximum 30.13 MJ/m^2 in 20^{th} of June and minimum 16.9 MJ/m^2 in 19th of December for Aswan). The Western Desert GSR regime is lower than that of the Upper Egypt but higher than that of the Middle Egypt (maximum 29.79 MJ/m^2 in 21^{th} of June, minimum 15.96 MJ/m^2 in 21^{th} of December for Kharga and maximum 29.65 MJ/m^2 in 24^{th} of June, minimum 13.85 MJ/m^2 in 23^{th} December for Asiut).

Figures 15, 16 show that the Mediterranean Sea region is similar to that of Cairo area in winter (minimum 10.33 MJ/m^2 in 24^{th} of December for Sidi-Barrani and 10.86 MJ/m^2 in 26^{th} of December for Mersa Matrouh). In summer, it is similar to that of Middle Egypt (maximum 29.13 MJ/m^2 in 24^{th} of June for Sidi-Barrani) or the Upper Egypt as in Mersa Matrouh (maximum 30.29 MJ/m^2 in 26^{th} of June).

CONCLUSIONS

A Typical Annual Time Function is obtained for 8 measurement stations, in Egypt, of daily GSR over a horizontal surface by the application of a computational method based on Fourier analysis.

The percentage of representation, for the data, obtained by yearly representative equation, corresponding to the first harmonic, varies between 73 % and 92 %. The Typical representative equation gives the mentioned percentage between 91 % and 97 %. The percentage of other harmonics is less than 2.5 %.

The climatological GSR regime of the Mediterranean Sea is similar to that of Upper Egypt region, in summer, and is similar to that of Cairo area, in winter.

The obtained Typical Annual Time Function, for each station, allows to estimate the most probable value of the GSR for every day of the year. The deviation of the annual average, of any year, from that obtained by the Typical Annual Time Function, in the period from 1981 to 1986, is less than 5 %.

REFERENCES

1. **J.M. Gordon and T.A. Reddy,** Time series analysis of daily horizontal Solar Radiation. Solar Energy 41 (3), 215 - 226 (1988).
2. **C.E.P. Brooks and N. Carruther,** Handbook of Statistical Methods in Meteorology, 2nd ed., 412 PP. Her Majesty's Stationary Office, London (1978).
3. **M.A.M. Shaltout,** Solar Energy Input to Egypt, Helwan Institute of Astronomy and Geophysics Bulletin, No. 271, 113 pp Egypt, (1981).
4. **A.M. Mehanna,** Meteorological Research Bulletin, Egypt, 8, p69 (1971).
5. **C.S. Alberto and J.M. Recio,** Fourier Analysis of Meteorological Data to obtain a Typical Annual Time Function. Solar Energy 32(4), 479 - 488 (1984).
6. **J.M. Baldasano, J. Clar and A. Berna,** Fourier analysis of daily Solar Radiation data in Spain. Solar Energy 41(4), 327 - 333 (1988).
7. **N.H. Helwa, M.T.Y. Tadros and M.A.H. Shaltout,** Simple Method for Computation of Solar Radiation for different Latitudes in Egypt. Indian Engineer (I) Journal - IDP, 68, 53 - 60 (1988).
8. **Solar Radiation and Radiation Balance Data.** The World Net Work, Voeikov Main Geophysical observatory, Leningrad, USSR (1981 - 1987).
9. **R.C. Balling, Jr.,** Harmonic analysis of monthly insolation levels in United States. Solar Energy 31(3), 293 - 298 (1983).

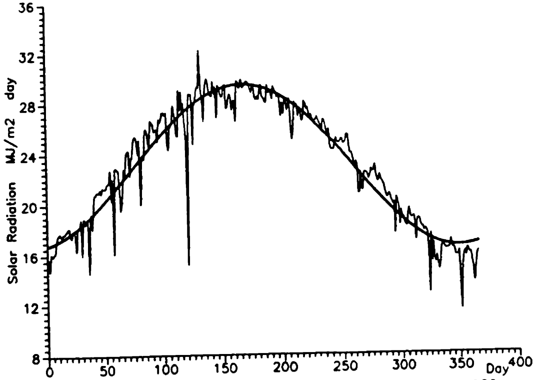

Fig.1.Annual variation of daily solar radiation in Aswan,1986.
Lat. 23° 58' N ,Long.32° 47' E.

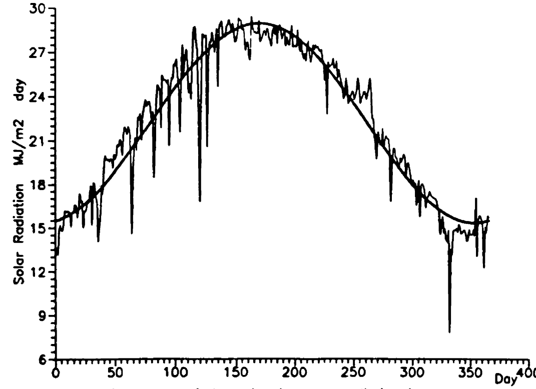

Fig.2.Annual variation of daily solar radiation in Kharga,1986.
Lat. 25° 27' N ,Long. 30° 32' E.

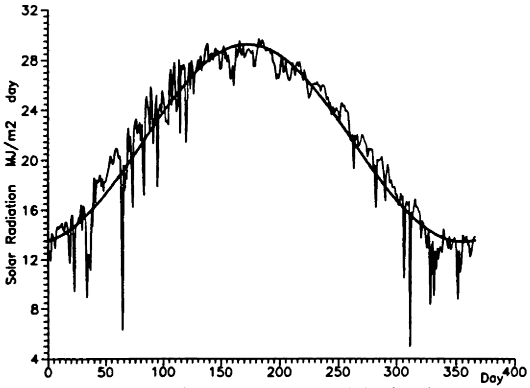

Fig.3.Annual variation of daily solar radiation in Asiut,1986.
Lat. 27° 03' N ,Long. 31° 03' E.

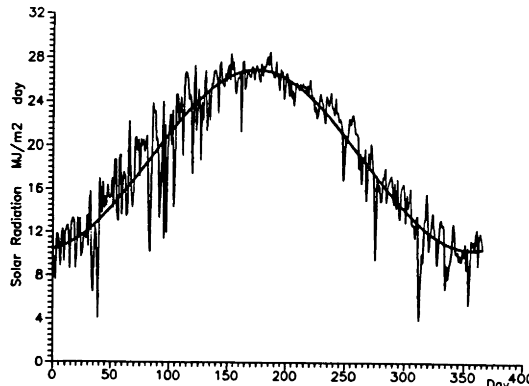

Fig.4.Annual variation of daily solar radiation in Cairo,1986.
Lat. 30' 05' N , Long. 31° 17' E.

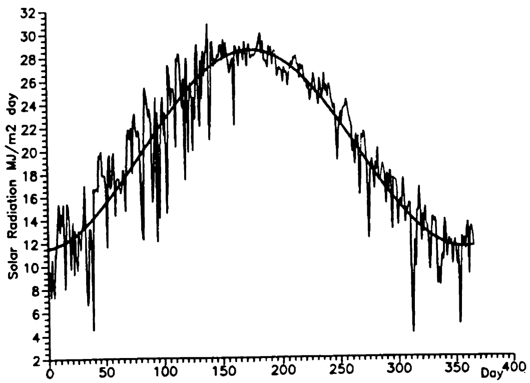

Fig.5.Annual variation of daily solar radiation in Bahtim,1986.
Lat. 30° 08' N , Long. 31° 15' E.

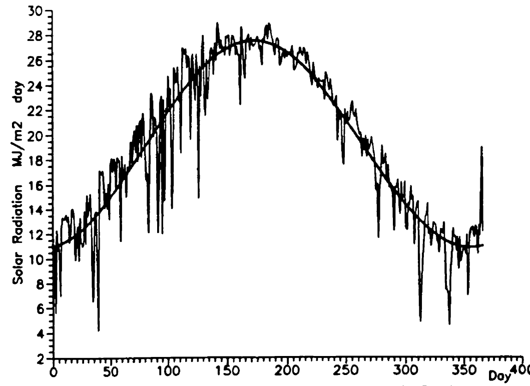

Fig.6.Annual variation of daily solar radiation in Tahrir,1986.
Lat. 30° 39' N , Long. 30° 42' E.

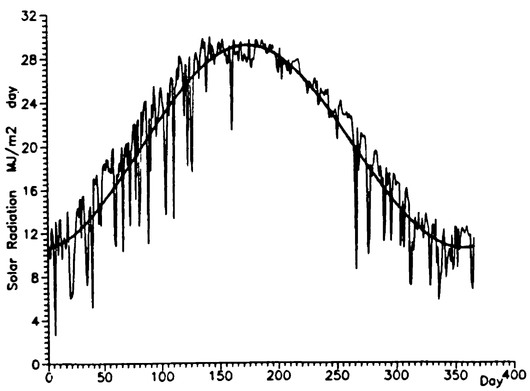

Fig.7.Annual variation of daily solar radiation in Mersa Matrouh,1986.
Lat. 31° 20' N , Long. 27° 13' E

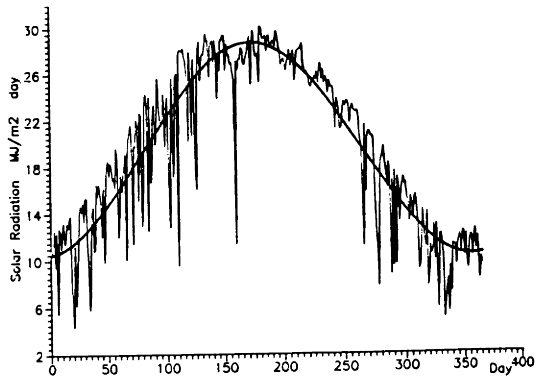

Fig.8.Annual variation of daily solar radiation in Sidi Barrani,1986.
Lat. 31° 38' N , Long. 25° 28' E.

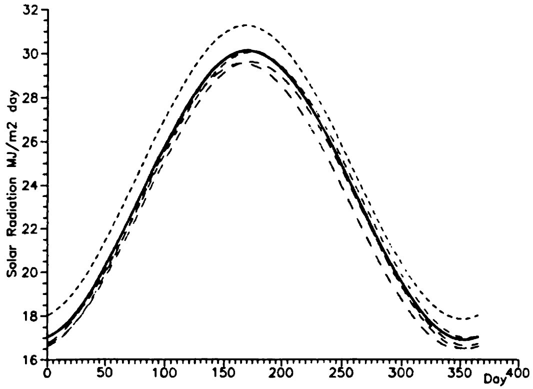

Fig 9.Representative equation of each year for Aswan.

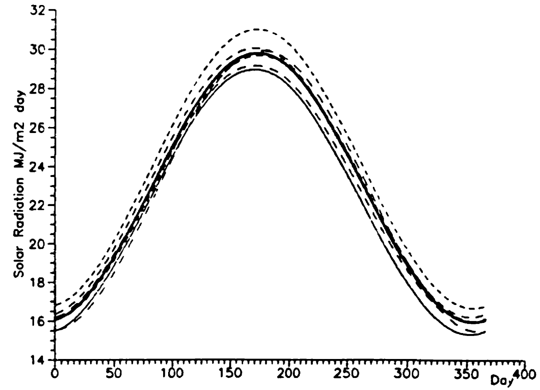

Fig.10.Representative equation of each year for Kharga.

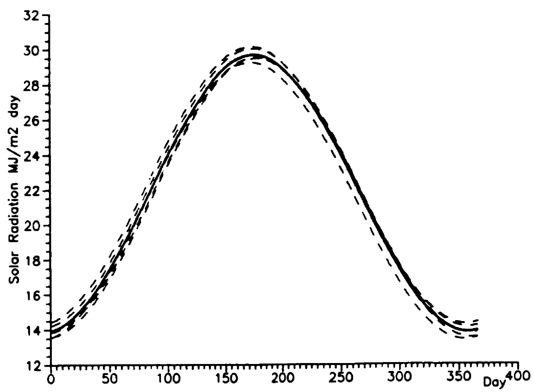

Fig.11.Representative equation of each year for Asiut .

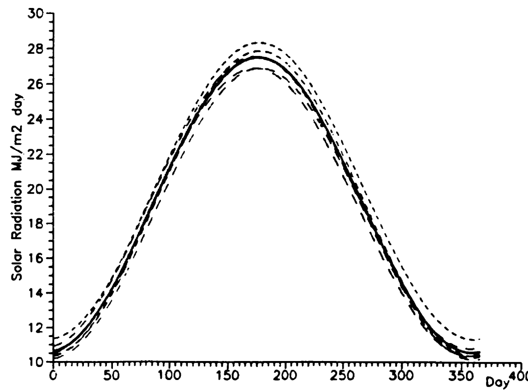

Fig.12.Representative equation of each year for Cairo.

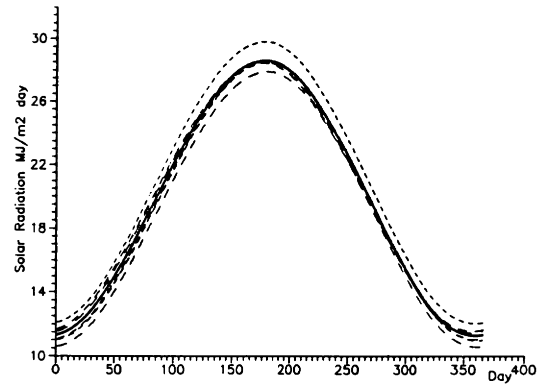

Fig.13.Representative equation of each year for Bahtim.

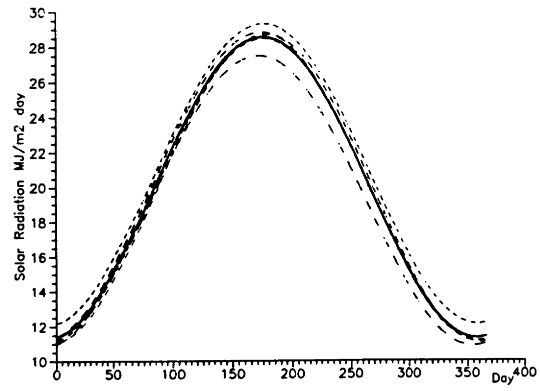

Fig.14.Representative equation of each year for Tahrir.

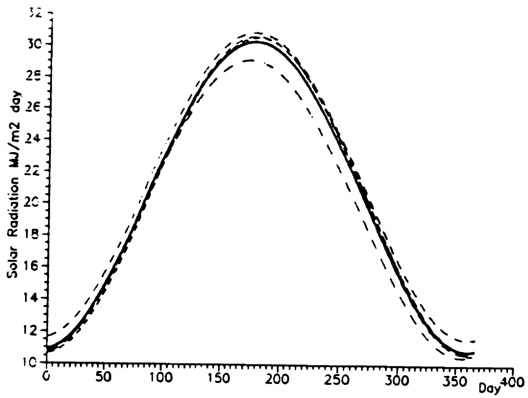

Fig.15.Representative equation of each year for Mersa Matrouh.

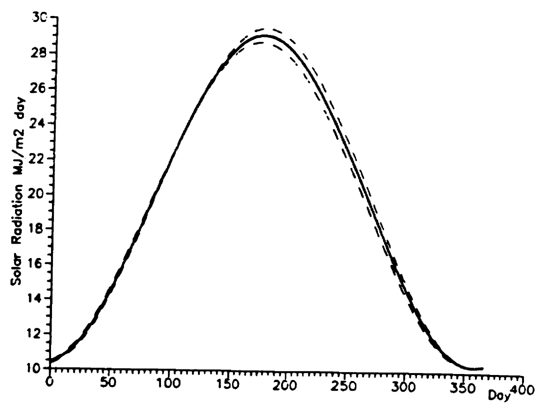

Fig 16.Representative equation of each year for Sidi-Barrani.