MAUSAM, 49, 1 (January 1998), 59-70

551.521.1(620)

Solar radiation characteristics at Qena / Egypt

SAYED M. EL -SHAZLY, A.M. ABDELMAGEED and M. EL-NOUBI ADAM

Department of Physics, Faculty of Science, South Valley University

Qena/Upper Egypt

(Received 20 November 1995, Modified 12 July 1996)

सार — जून 1992 से मई 1993 तक की अवधि में केना/मिस्र के उत्तरी भाग में क्षैतिज सतह पर घंटेवार भूमंडलीय सौर विकिरण (*G*) और उसके विसरित घटक (*D*) का मूल्यांकन किया गया है। इसमें संगत विसरित अंश (*D/G*) का आकलन किया गया है। परिणामों की दैनिक भिन्नताओं का अध्ययन किया गया है। दैनिक कुल मानों और उनके मासिक तथा सामयिक औसत के साथ-साथ उनकी आवृत्ति के वितरणों का भी आकलन और परीक्षण किया गया है। परिणामों के उतार-चढ़ाव पर मौसमी और जलवायवी प्रभावों की भी इसमें चर्चा की गई है। बसन्त और शीत ऋतु के महीनों में मेघों के परिमाण, जल की मात्रा और ऐरॉसोल धूल कणों की सांद्रता के कारण वायुमंडलीय परिस्थितियों में आए अधिक उतार-चढ़ाव से ये प्रभाव विशेष रूप से अधिक समय तक रहे। मेघों के प्रभाव की भी इसमें चर्चा की गई है। बादलों का प्रभाव परिणामों को बहुत कम (4.5 प्रतिशत) प्रभावित करता है। अध्ययन क्षेत्र में बादलों की कम संख्या में इस तथ्य का पता चलता है। विसरण खंड और क्लिअरनैस सूची (*G/Go*) के बीच संबंधों से यह पता चलता है कि ऐसे अधिकांश स्थल आगत और विकिरण की उच्चस्थिति के क्षेत्र में पाए जाते हैं। सामान्यतः इस अध्ययन से यह स्पष्ट पता चलता है कि केना/मिस्र में सौर ऊर्जा प्रचुर मात्रा में है, और वहां की जलवायु इस ऊर्जा के विभिन्न उपयोगों के लिए अनुकूल है।

ABSTRACT. Measurements of the hourly global solar radiation(G) and its diffuse component(D) on a horizontal surface have been carried out in Qena/Upper Egypt in the period from June 1992 to May 1993. The corresponding diffuse fraction (D/G) is calculated. Diurnal variations of the results have been studied. Also the daily totals values and its monthly and seasonal averages as well as their frequency distributions were computed and examined. The seasonal and climatic effects on the fluctuation of the results are discussed. These effects were particularly large during Spring and Winter months owing to the high fluctuation of the atmospheric conditions with respect to amount of clouds, water content, and concentration of aerosol dust particles. The influence of clouds is also considered. It shows small effect on the results (4.5%), reflecting the low degree of cloudiness in the study region. The relation between the diffuse fraction and clearness index (G/G_o) shows that most of the points lies in the region of the high availability of the incoming solar radiation. In general the study shows clearly the abundance of solar energy in Qena/Egypt, and the suitability of its climate for using it in different applications.

Key words — Solar radiation, Global solar radiation, Diffuse solar radiation, Diffuse fraction of global solar radiation, Clearness index, Radiation.

1. Introduction

Over the past years, a decided need for additional solar radiation data has developed due to the increased use of solar energy systems. The detailed knowledge of these data is of fundamental importance to the successful development of projects for the practical utilization of solar energy by agriculturists, hydrologists, architects and engineers, particularly in the region where sunshine is available in abundance (Atwater and Ball 1981, Moriarity 1991, Kuye and Jagtap 1992, Neuwirth 1980).

Qena is a city of abundant solar radiation for the most months of the year. Accordingly, it would appear to be well suited for the use of solar energy in different application owing to the interest, which this form of clean energy presents to solve the energy demand problems. In this concern we attempt, in this study, to provide solar radiation

TABLE 1

Results of mean values of hourly and daily global solar radiation (MJ m^{-2}) in all (Ga) and cloudless (Gc) sky conditions in the period from June 1992 to May 1993

Period	Global Solar radiation	LAT															Daily totals
		Sr-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-Ss	
Jun '92	Ga	0.01	0.31	1.02	1.85	2.58	3.18	3.59	3.75	3.66	3.34	2.79	2.08	1.26	0.49	0.04	29.96
	Gc	0.01	0.31	1.03	1.86	2.59	3.19	3.60	3.75	3.67	3.35	2.80	2.09	1.27	0.49	0.04	30.09
July	Ga	0.00	0.28	1.00	1.81	2.53	3.12	3.54	3.74	3.66	3.33	2.76	2.03	1.23	0.45	0.03	29.56
	Gc	0.00	0.28	1.00	1.81	2.53	3.12	3.54	3.74	3.66	3.34	2.77	2.04	1.25	0.46	0.03	29.59
Aug	Ga		0.16	0.82	1.64	2.38	2.95	3.43	3.62	3.52	3.17	2.59	1.84	1.01	0.28	0.01	27.31
	Gc		0.16	0.82	1.64	2.39	2.96	3.43	3.63	3.53	3.16	2.58	1.84	1.00	0.28	0.01	27.38
Sep	Ga		0.06	0.60	1.46	2.22	2.80	3.24	3.42	3.33	2.96	2.33	1.56	0.74	0.11		24.74
	Gc		0.06	0.60	1.43	2.22	2.80	3.24	3.42	3.33	2.97	2.33	1.56	0.75	0.11		24.83
Oct	Ga		0.01	0.32	1.08	1.83	2.47	2.88	3.03	2.95	2.56	1.96	1.19	0.44	0.02		20.75
	Gc		0.01	0.32	1.09	1.83	2.47	2.89	3.05	2.97	2.59	1.99	1.21	0.44	0.02		20.98
Nov	Ga			0.13	0.70	1.36	2.01	2.42	2.58	2.46	2.14	1.57	0.90	0.24	0.00		16.52
	Gc			0.12	0.68	1.40	1.99	2.40	2.58	2.50	2.17	1.61	0.93	0.24	0.00		16.78
Dec	Ga			0.03	0.45	1.10	1.65	2.07	2.34	2.26	2.01	1.55	0.93	0.28	0.01		14.68
	Gc			0.03	0.43	1.08	1.68	2.12	2.36	2.34	2.08	1.58	0.93	0.26	0.01		15.05
Jan' 93	Ga			0.00	0.21	0.84	1.49	2.00	2.33	2.39	2.26	1.79	1.25	0.59	0.10		15.25
	Gc			0.00	0.22	0.89	1.60	2.15	2.48	2.59	2.46	2.07	1.45	0.71	0.12		16.69
Feb	Ga			0.01	0.35	1.11	1.82	2.41	2.79	2.93	2.77	2.31	1.73	1.00	0.28	0.00	19.51
	Gc			0.01	0.36	1.12	1.82	2.41	2.85	2.96	2.18	2.37	1.77	1.03	2.28	0.00	20.29
Mar	Ga		0.00	0.09	0.64	1.44	2.21	2.82	3.18	3.29	3.09	2.66	2.00	1.19	0.40	0.01	23.09
	Gc		0.00	0.10	0.70	1.49	2.28	2.86	3.20	3.33	3.14	2.65	1.94	1.14	0.39	0.01	23.52
Apr	Ga		0.03	0.39	1.14	1.83	2.61	3.16	3.43	3.49	3.10	2.67	2.00	1.25	0.47	0.03	25.60
	Gc		0.03	0.39	1.22	2.02	2.71	3.28	3.48	3.60	3.35	2.84	2.09	1.35	0.51	0.03	27.22
May	Ga		0.12	0.72	1.54	2.22	2.79	3.25	3.55	3.51	3.00	2.55	1.94	1.18	0.67	0.04	26.90
	Gc		0.12	0.73	1.58	2.30	2.85	3.44	3.72	3.77	3.52	2.97	2.25	1.38	0.55	0.04	29.24
Summer	Ga	0.01	0.20	0.86	1.68	2.40	2.98	3.41	3.60	3.51	3.17	2.59	1.85	1.05	0.33	0.03	27.61
	Gc	0.04	0.20	0.87	1.69	2.44	3.01	3.46	3.65	3.56	3.21	2.63	1.89	1.08	0.33	0.03	28.17
Autumn	Ga		0.01	0.22	0.86	1.56	2.19	2.61	2.78	2.67	2.35	1.77	1.07	0.36	0.03		18.40
	Gc		0.01	0.22	0.87	1.59	2.21	2.63	2.80	2.73	2.39	1.82	1.09	0.37	0.03		19.17
Winter	Ga			0.02	0.32	1.03	1.70	2.24	2.61	2.69	2.51	2.06	1.49	0.77	0.19	0.01	17.37
	Gc			0.02	0.33	1.06	1.76	2.34	2.70	2.84	2.71	2.26	1.63	0.87	0.19	0.01	18.85
Spring	Ga	0.01	0.14	0.63	1.42	2.13	2.79	3.29	3.54	3.54	3.15	2.69	2.02	1.24	0.48	0.03	27.18
	Gc	0.01	0.14	0.64	1.49	2.25	2.89	3.41	3.63	3.65	3.38	2.86	2.13	1.32	0.51	0.03	28.71
Year	Ga	0.01	0.15	0.48	1.09	1.80	2.43	2.90	3.14	3.11	2.80	2.28	1.61	0.85	0.28	0.03	22.64
	Gc	0.03	0.15	0.49	1.11	1.86	2.50	2.98	3.20	3.19	2.92	2.38	1.66	0.89	0.28	0.03	23.72

information for the designers of solar energy utilization systems under the climatic conditions of Qena/Egypt, which may also serve as a useful reference for system designers and users in other regions, with similar climatic conditions.

In this work we study the characteristics of global solar radiation(G), its diffused component (D) and its corresponding fraction(K) in different sky conditions.

2. General climate of Qena/Egypt

Qena is located in the south part of Egypt at latitude 26°10′ N, longitude 32° 43′ E and elevation 78m above sea level. Climatically (Meteorological Department of A.R. Egypt), Qena lies within the subtropical region and characterized with hot, dry and calm weather. Also it is almost cloudless (80% of the days of the year is cloudless) and

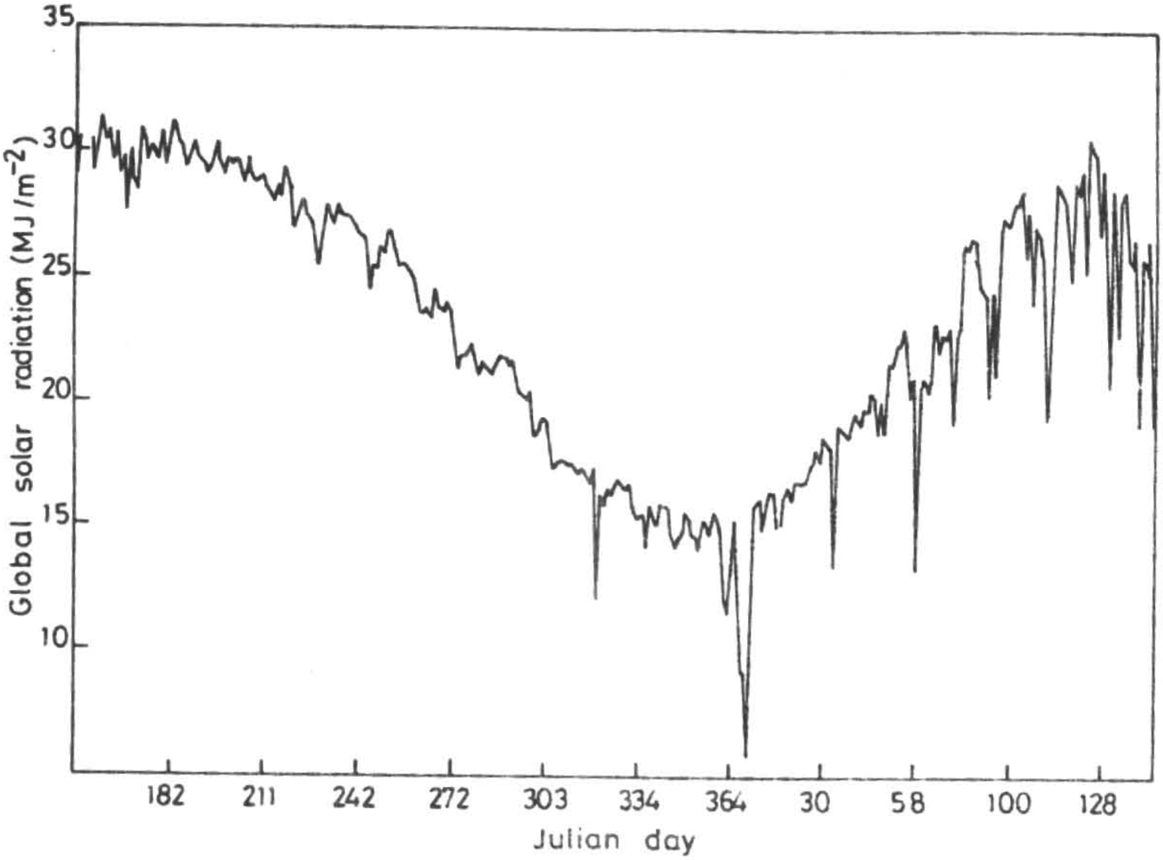

Fig.1 Variation of daily totals of global solar radiation (June 1992-May 1993)

rainless. Average temperature ranges from 14.5°C in January to 34°C in July. Average relative humidity varies from 21% in May and June to 48% in December. Significant percentage of winds is calm (≅52%). The prevailing winds are W, NW, SW and N with percentages of occurrence as 15.9%, 11.83%, 11.7% and 4.52% respectively. The major wind ranges from 2 to 3.1 m s^{-1} and the least occurrence speed ranges from 8.8 to 10.8 m s^{-1}.

3. Measurements

Measurements of global (G) and diffuse (D) solar radiation have been done hourly from sunrise to sunset in the period from June 1992 to May 1993, using two Kipp and Zonen pyranometers (Model CM 6B). One of them is used to measure the global solar radiation and the other is fitted with a shadow band of radius 610 mm and width 50 mm, constructed following Kipp and Zonen design, to measure its diffuse component. The pyranometer specifications meet the majority of the requirements set for class I radiation sensors by the World Meteorological Organization (WMO 1983). The setting of the shadow band was checked twice daily making sure of the centering of the sun shade on the receiver head of the pyranometer all day around. Every few days the band position is adjusted according to the actual declination of the sun. Irradiances (G and D) in W m^{-2} were measured and integrated over 60 minutes period using a two channels solar integrator (Kipp and Zonen Model CC12). The measurement instruments were used for the first time in this study and calibrated by the manufacturers themselves. The pyranometer has a directionality error <20 Wm^{-2} at 100 W m^{-2} and a nonlinearity <1.5%(<1000Wm^{-2}), while the inaccuracy of the solar integrator lies within 0.2% ±1 digit. The measured values of D were multiplied by a correction factor f (1 to 1.14), calculated daily to compensate the small part of the diffuse sky radiation, which is obstructed by the shadow band. This

TABLE 2

Percentage of frequency distribution of daily totals of global solar radiation through the measurement period in Qena/Egypt

Range MJ m^{-2}	0-5	5-10	10-15	15-20	20-25	25-30	30-35
Jun 1992	0.0	0.0	0.0	0.0	0.0	40.7	59.3
Jul	0.0	0.0	0.0	0.0	0.0	81.5	18.5
Aug	0.0	0.0	0.0	0.0	0.0	100.0	0.0
Sep	0.0	0.0	0.0	0.0	52.0	48.0	0.0
Oct	0.0	0.0	0.0	22.2	77.8	0.0	0.0
Nov	0.0	0.0	4.0	96.0	0.0	0.0	0.0
Dec	0.0	0.0	53.8	46.2	0.0	0.0	0.0
Jan 1993	0.0	11.5	7.7	80.8	0.0	0.0	0.0
Feb	0.0	0.0	7.7	50.0	42.3	0.0	0.0
Mar	0.0	0.0	0.0	6.3	68.8	25.0	0.0
Apr	0.0	0.0	0.0	7.4	29.6	63.0	0.0
May	0.0	0.0	0.0	8.7	8.7	73.9	8.7
Summer	0.0	0.0	0.0	0.0	17.3	76.5	6.2
Autumn	0.0	0.0	19.3	54.8	25.9	0.0	0.0
Winter	0.0	3.8	5.1	45.7	37.0	8.3	0.0
Spring	0.0	0.0	0.0	5.4	12.8	59.2	22.7
Year	0.0	1.0	6.1	26.5	23.3	36.0	7.2

value is determined by Latimer and Mac Dowall (1971) as follows:

$$f = 1/(1 - F/D) \quad (1)$$

in which assuming the isotropic distribution of sky radiance,

$$F/D = (2\,\omega/\pi r)\cos^3\delta\,(\sin\phi\sin\delta\,H_o + \cos\phi\cos\delta\sin H_o) \quad (2)$$

where, ω is the width of the band, r is its radius, δ is the solar declination, ϕ is the station latitude and H_o is the hour angle of the sun at sunset.

4. Result and discussion

The different solar radiation components are functions of several variables (Atwater and Ball 1981, Kudish *et al.* 1983) such as the solar elevation angle (solar height), the nature and extent of cloudiness (Cloud amount), the atmospheric scattering by air molecules, (Rayleigh scattering) and aerosols (Mie scattering) as well as the absorption by atmospheric gases (H_2O, O_2, CO_2, O_3 in specific wavelength bands) and aerosols. The values and variations of these components are mainly influenced by the mentioned parameters, which will be considered in this chapter to discuss the measurement results in the different periods of the year.

4.1. *Characteristics of global solar radiation (G) on a horizontal surface*

4.1.1. *All sky conditions measurements* (G_a)

(a) *Hourly variation of global solar radiation* (G_{ah})

Table 1 gives the average values of the hourly global solar radiation in MJ m^{-2} received on a horizontal surface through a day in different months during the measurement period (Local Apparent Time, LAT, is used). From this table one can see clearly that the rise and fall of the hourly global solar radiation throughout the day is generally symmetrical with respect to the solar noon for all days the year around. As expected the maximum values are recorded at midday hours (11-13 LAT) with average values range from 3.75/3.74 MJ m^{-2} in June/July to 2.26 MJ m^{-2} in December in somewhat symmetrical way, while the minimum values were observed at "early morning" (Sunrise till 7 LAT) and "late afternoon" (17 till Sunset LAT) with average value being in some measurements in the order of the instrument offset. This behavior is a resultant of the longer path traversed by the solar radiation in the early morning and late afternoon ($0.8° \equiv h \equiv 15.5°$) than in the solar noon time ($39.9° \equiv h \equiv 81.4°$). This is accompanied with greater amount of scattering and absorption and leads to marked depletion of the global solar radiation in the early morning and late afternoon hours compared to the noon time.

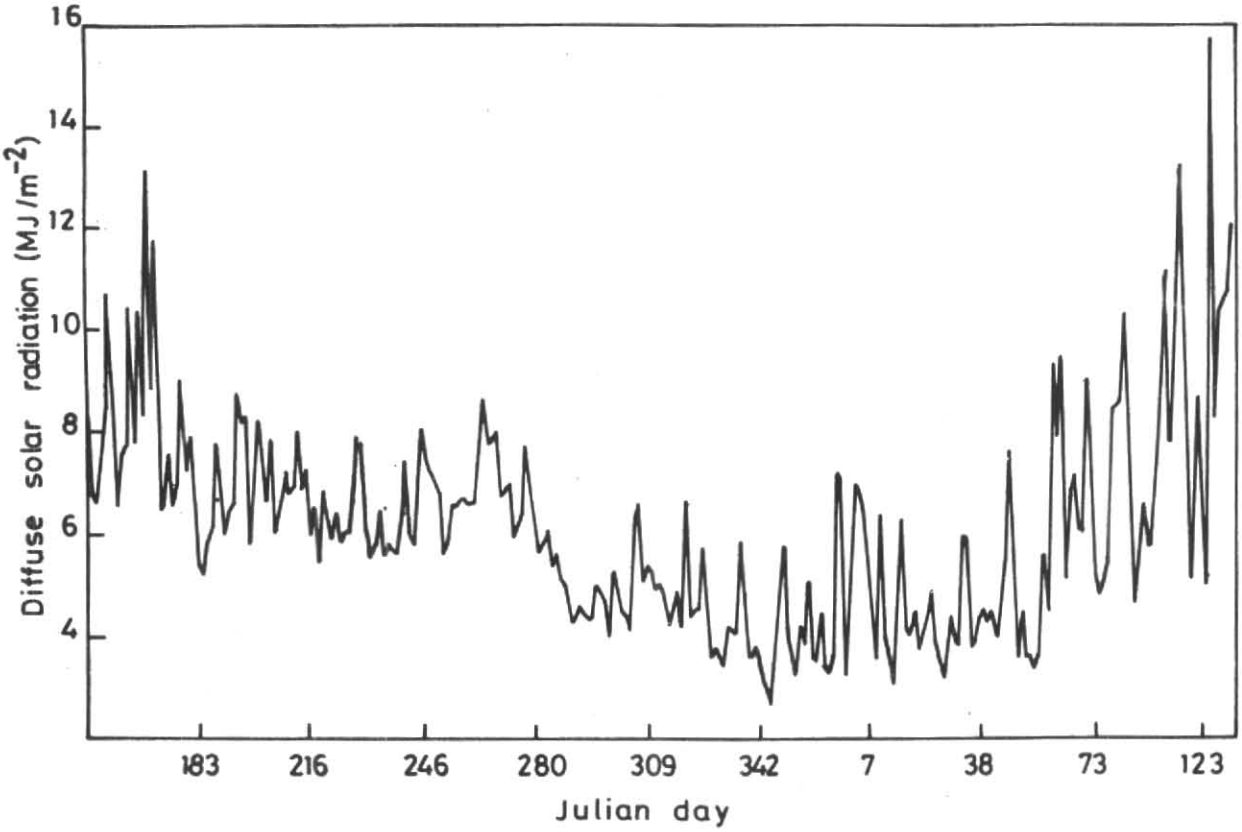

Fig.2. Variation of daily totals of diffuse solar radiation (June 1992-May 1993)

(b) *Variation of daily totals of global solar radiation* (G_{ad})

Fig. 1 illustrates the variation of the daily totals of global solar radiation through the whole measurement period from June 1992 to May 1993. The value of G_{ad} varies from 31.37 MJ m^{-2} [on the day number 159 (8 June)] to 5.63 MJ m^{-2} [on the day number 7 (7 Jan)] with somewhat remarkable variation from day-to-day. This variation is due to the fluctuation of the atmospheric conditions with respect to water content, dust and amount and type of clouds, which change from hour-to-hour and day-to-day.

(*i*) *Variation of monthly average of daily totals of global solar radiation* (G_{ad})

The variations of the monthly average of G_{ad} are also included in Table 1. The average value of daily totals of G_{ad} ranges from 29.96 MJ m^{-2} in June to 14.68 MJ m^{-2} in December. The maximum value of extraterrestrial radiation at the places outside the tropics in the northern hemisphere G_0, occurs in June (G_0 = 40.914 MJ m^{-2}) and the minimum in December (G_0 = 22.277 MJ m^{-2})C Morris *et al.* 1982). The results of the monthly average of G_{ad} show that the standard deviation has relatively high values in May (±869), January (±829), and April (±749), compared with the small values in July (±194) and June (±246). This is due to the strong fluctuation of atmospheric dust particles and clouds in these three months (May, January, and April).

(*ii*) *Variation of seasonal averages of* G_{ad}

Table 1 gives the seasonal averages of G_{ad} as well as its average over the whole measurement period. From this table one can see that the average G_{ad} over the year is 22.64 MJ m^{-2} with a seasonal variation from 17.37 MJ m^{-2} in winter to 27.61 MJ m^{-2} in summer. This relatively temperate variation is typical of the climate of North Africa and also reflects the low degree of cloudiness in the study region (1octa in average through the measurement period). The standard deviation of the results, has high values in winter (±1023) and spring (±864) and a small value in summer

TABLE 3

Results of mean values of hourly and daily diffuse solar radiation (MJ m^{-2}) in all (Da) and cloudless(Dc) sky conditions in the period from June 1992 to May 1993

Period	Diffuse Solar radiation	LAT															Daily totals
		Sr-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-Ss	
Jun'92	Da	0.006	0.202	0.451	0.619	0.726	0.788	0.817	0.852	0.844	0.805	0.742	0.657	0.530	0.300	0.038	8.376
	Dc	0.006	0.202	0.442	0.605	0.709	0.765	0.788	0.826	0.825	0.788	0.723	0.642	0.521	0.297	0.037	8.177
Jul	Da	0.004	0.162	0.372	0.512	0.598	0.653	0.687	0.699	0.697	0.659	0.627	0.550	0.429	0.239	0.026	6.912
	Dc	0.005	0.164	0.373	0.511	0.599	0.653	0.685	0.695	0.684	0.647	0.617	0.543	0.426	0.241	0.028	6.871
Aug	Da		0.099	0.346	0.507	0.554	0.610	0.642	0.646	0.650	0.619	0.597	0.498	0.370	0.160	0.008	6.309
	Dc		0.093	0.345	0.508	0.534	0.586	0.615	0.625	0.616	0.587	0.548	0.484	0.376	0.150	0.006	6.060
Sept	Da		0.051	0.307	0.516	0.649	0.726	0.765	0.782	0.766	0.724	0.666	0.554	0.357	0.113		6.995
	Dc		0.046	0.302	0.506	0.627	0.702	0.736	0.762	0.742	0.700	0.640	0.530	0.357	0.086		6.737
Oct	Da		0.006	0.176	0.377	0.479	0.575	0.606	0.622	0.603	0.578	0.509	0.400	0.219	0.018		5.168
	Dc		0.006	0.179	0.375	0.482	0.565	0.592	0.604	0.583	0.559	0.489	0.390	0.215	0.017		5.055
Nov	Da			0.087	0.304	0.442	0.531	0.594	0.572	0.559	0.537	0.498	0.379	0.166	0.000		4.670
	Dc			0.085	0.298	0.441	0.527	0.574	0.547	0.545	0.510	0.435	0.363	0.161	0.002		4.489
Dec	Da			0.025	0.207	0.375	0.480	0.507	0.554	0.541	0.495	0.430	0.357	0.178	0.008		4.158
	Dc			0.028	0.208	0.373	0.450	0.480	0.511	0.461	0.432	0.374	0.329	0.161	0.007		3.813
Jan'93	Da			0.004	0.137	0.316	0.466	0.541	0.574	0.620	0.613	0.510	0.426	0.266	0.060		4.535
	Dc			0.000	0.127	0.282	0.398	0.469	0.487	0.515	0.491	0.445	0.373	0.257	0.076		3.919
Feb	Da			0.007	0.163	0.356	0.483	0.572	0.596	0.592	0.578	0.519	0.432	0.346	0.141	0.004	4.788
	Dc			0.007	0.165	0.341	0.461	0.531	0.524	0.507	0.500	0.485	0.396	0.315	0.142	0.004	4.376
Mar	Da			0.063	0.300	0.502	0.603	0.683	0.717	0.745	0.731	0.706	0.643	0.480	0.224	0.012	6.408
	Dc			0.070	0.326	0.541	0.647	0.710	0.713	0.741	0.720	0.669	0.608	0.476	0.244	0.014	6.479
Apr	Da		0.016	0.228	0.471	0.620	0.668	0.763	0.806	0.767	0.774	0.719	0.629	0.452	0.224	0.019	7.156
	Dc		0.021	0.254	0.517	0.618	0.593	0.643	0.709	0.656	0.663	0.640	0.593	0.450	0.256	0.022	6.635
May	Da		0.097	0.389	0.502	0.635	0.954	1.008	1.011	0.991	0.881	0.831	0.672	0.479	0.262	0.035	8.747
	Dc		0.096	0.423	0.531	0.596	0.663	0.724	0.792	0.825	0.742	0.709	0.558	0.419	0.261	0.028	7.366
Summer	Da	0.005	0.123	0.364	0.522	0.603	0.662	0.695	0.708	0.701	0.667	0.633	0.539	0.403	0.186	0.024	6.835
	Dc	0.005	0.115	0.353	0.511	0.590	0.648	0.678	0.692	0.678	0.641	0.599	0.520	0.389	0.172	0.025	6.616
Autumn	Da		0.011	0.126	0.335	0.468	0.550	0.595	0.606	0.582	0.553	0.488	0.393	0.200	0.027		4.934
	Dc		0.011	0.137	0.342	0.475	0.554	0.590	0.598	0.576	0.547	0.475	0.392	0.209	0.029		4.936
Winter	Da			0.016	0.172	0.371	0.509	0.582	0.612	0.644	0.626	0.558	0.462	0.321	0.104	0.007	4.985
	Dc			0.014	0.162	0.335	0.446	0.515	0.533	0.522	0.508	0.475	0.396	0.295	0.115	0.004	4.320
Spring	Da	0.006	0.113	0.346	0.565	0.697	0.771	0.912	0.902	0.891	0.849	0.795	0.694	0.520	0.276	0.027	8.363
	Dc	0.006	0.133	0.373	0.565	0.671	0.706	0.743	0.798	0.784	0.751	0.699	0.622	0.495	0.281	0.029	7.655
Year	Da	0.006	0.101	0.229	0.390	0.524	0.613	0.679	0.691	0.688	0.658	0.603	0.508	0.348	0.155	0.022	6.214
	Dc	0.005	0.104	0.251	0.402	0.518	0.590	0.630	0.647	0.635	0.607	0.559	0.479	0.338	0.158	0.023	5.947

indicating the higher stability of the atmosphere in the summer months.

(iii) Percentage frequency distribution of G_{ad}

The percentage frequency distributions of G_{ad} are given in Table 2 for each month, season and the whole period, respectively. From this table, it can be seen that about 93% of the days in the year have values of G_{ad} within the range from 15-35 MJ m^{-2}. In summer and spring months, 82.7% and 81.9%, respectively of occurrences are in the range of 25-35 MJ m^{-2}, while in autumn and winter, 80.7% and 82.7%, respectively are in the range 15-25 MJ m^{-2}. In June, July and August, almost all days receive G_{ad} in the range of 25-35 MJ m^{-2} and 59.3% of these days get between 30 and 35 MJ m^{-2} in June. The above

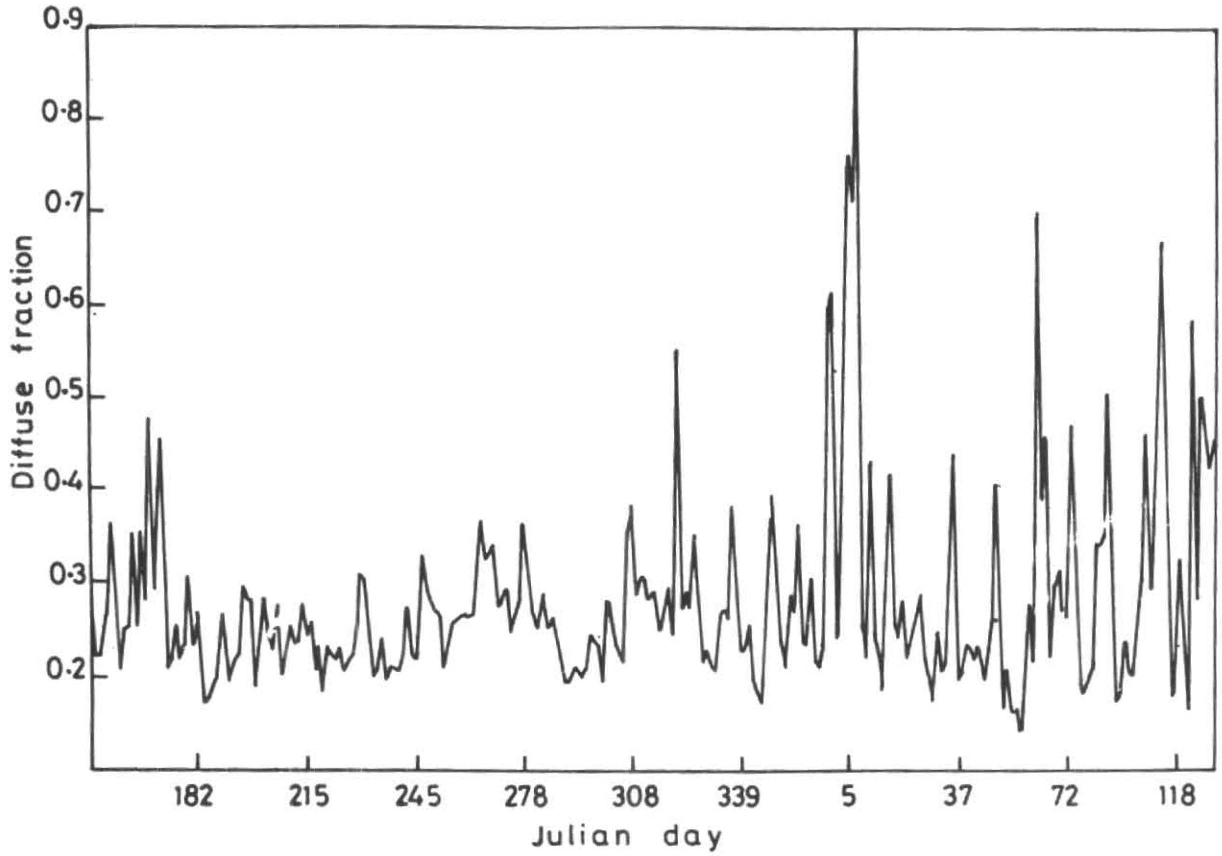

Fig. 3. Variation of daily diffuse fraction (June 1992-May 1993)

distribution of the solar radiation is characteristic for the subtropical regions and indicates to the richness of the study region with solar energy.

4.1.2. *Comparison between global solar radiation in all (G_a) and cloudless (G_c) sky conditions [Table 1]*

(*a*) *Comparison between the hourly global solar radiation in all (G_{ah}) and cloudless (G_{ch}) sky conditions*

A comparative study between the average values of G_{ch} and G_{ah} in the whole measurement period shows that:

(*i*) the course of G_{ch} is similar to that of G_{ah} with somewhat higher values of G_{ch}, because of the missing attenuation by clouds.

(*ii*) the average clouds effect seems to be small in Qena over the whole measurement period because the small attenuation in some months acts oppositely to the higher values in other months. Also Qena is characterized with high and thin clouds, which causes less depletion of the global solar radiation.

(*b*) *Comparison between the daily totals of global solar radiation in all (G_{ad}) and cloudless (G_{cd}) sky conditions ones*

The behaviour of G_{cd} shows the same general pattern as G_{ad} for both monthly and seasonal averages, but with higher values. The relative percentage when G_{cd} exceeds G_{ad} was found to be maximum in January (9%), May(8%) and winter (7.9%), while it is minimum in July (0.1%) and summer (2%). In the whole period the average value is (4.6%). This is due to the clouds, which was maximum in January (1.79 octas) and May (2.68 octas) and in winter (1.61 octas), while it was minimum in July (0.08 octa) and summer (0.11 octa). The average values of G_{cd} varies from 30.09 MJ m^{-2} in June to 15.05 MJ m^{-2} in December and from 28.71 MJ m^{-2} in spring to 18.85 MJ m^{-2} in winter with the average value over the whole measurement period being 23.72 MJ m^{-2}.

TABLE 4

Percentage of frequency distribution of daily totals of diffuse solar radiation through the measurement period

Range (MJ m^{-2})	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16
Jun' 92	0.00	0,00	0.00	57.69	23.08	15.38	3.85	0.00
Jul	0.00	0.00	25.00	58.33	16.67	0.00	0.00	0.00
Aug	0.00	0.00	44.44	55.56	0.00	0.00	0.00	0.00
Sep	0.00	0,00	12.00	76.00	12.00	0.00	0.00	0.00
Oct	0.00	3.85	76.92	19.23	0.00	0.00	0.00	0.00
Nov	0.00	16.67	75.00	8.33	0.00	0.00	0.00	0.00
Dec	0.00	61.54	30.77	7.69	0.00	0.00	0.00	0.00
Jan' 93	0.00	40.00	40.00	20.00	0.00	0.00	0.00	0.00
Feb	0.00	39.13	47.83	8.70	4.35	0.00	0.00	0.00
Mar	0.00	0.00	38.46	38.46	23.08	0.00	0.00	0.00
Apr	0.00	0.00	28.57	23.81	28.57	14.29	4.76	0.00
May	0.00	0.00	12.50	12.50	12.50	50.00	0.00	12.50
Jun' 92	0.00	0,00	0.00	57.69	23.08	15.38	3.85	0.00
Summer	0.00	0.00	27.15	63.30	9.56	0.00	0.00	0.00
Autumn	0.00	27.35	60.90	11.75	0.00	0.00	0.00	0.00
Winter	0.00	26.38	42.10	22.39	9.14	0.00	0.00	0.00
Spring	0.00	0.00	13.69	31.33	21.38	26.56	2.87	4.17
Year	0.00	13.43	35.96	32.19	10.02	6.64	0.72	1.04

4.2. *Characteristics of diffuse solar radiation* (D)

4.2.1. *All sky conditions measurements* (D_a)

(*a*) *Hourly variation of diffuse solar radiation(Dah)*

Table 3 gives the results of hourly variation of diffuse solar radiation in MJ m^{-2} through the measurement period. The measured mean values of D_{ah} are maximum in the hours around midday (11-13 LAT). Its average value over the whole measurement period is equal to 0.69 MJ m^{-2}, ranging from 0.85 MJ m^{-2} in June to 0.54 MJ m^{-2} in December. At early morning (Sunrise till 7 LAT) and late afternoon (17 till - sunset LAT) hours, the recorded values are minimum, with average value during the whole period ranging from 0.01 to 0.23 MJ m^{-2}.

(*b*) *Variation of monthly and seasonal averages of daily totals of diffuse solar radiation* (D_{ad})

The variation of D_{ad} through the measurement period is graphically represented in Fig. 2. The value of D_{ad} fluctuates highly from day to day according to the state of the atmospheric conditions (water content, amount of cloud, aerosol particles, etc). It ranges from 15.70 MJ m^{-2} on 8 May to 2.64 MJ m^{-2} on 10 Dec. The variation of monthly and seasonal averages of D_{ad} are also given in the Table 3. It was maximum in May (8.75 MJ m^{-2}) and during the spring (8.36 MJ m^{-2}), and minimum in December (4.16 MJ m^{-2}) and during the winter (4.99 MJ m^{-2}). In general the fluctuation of the average D_{ad} through the months and the seasons of the year reflects the effect of the atmospheric conditions especially the amount of clouds and aerosol particles. Relatively high amounts of clouds and atmospheric particles lead to the maximum values of D_{ad} in May and during the spring, while the minimum values of D_{ad}, which occur in December and during the winter are mainly due to the astronomical factors. The average value of D_{ad} for the whole period of measurements is equal to 6.21 MJ m^{-2}, that means only about 27% of the corresponding value of G_{ad} (22.64 MJ m^{-2}). This conclusion refers to the low degree of cloudiness in Qena, which makes it an ideal region for using the solar energy for different applications.

(*c*) *Frequency distributions of* D_{ad}

The percentage frequency distributions of D_{ad} in different months, seasons and the whole measurement period are summarized in Table 4. The percentage frequency of D_{ad} received on a horizontal surface is very low in the range > 14 MJ m^{-2} compared to that for the corresponding global solar radiation (G_{ad}) (see Table 2). About 91.6% of the days in the year have the values of D_{ad} within the low range 2-10 MJ m^{-2}. This clarifies the conclusion that Qena city is a suitable region for utilizing the solar energy.

4.2.2. *Comparison between diffuse solar radiation in all* (D_a) *and cloudless* (D_c) *sky conditions*

The results of diffuse solar radiation measurements in cloudless sky conditions (D_c) are summarized in Table 3. A comparison study has been done between

TABLE 5

Results of mean values of hourly and daily diffuse fraction of global solar radiation in all(ka) and cloudless(kc) sky conditions in the period from June 92 to May 93

Period	Diffuse fraction of Global solar Solar radiation	LAT Sr-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-Ss	Daily totals
Jun' 92	ka	0.78	0.65	0.46	0.34	0.28	0.25	0.23	0.23	0.24	0.24	0.27	0.32	0.43	0.62	0.92	0.28
	kc	0.78	0.64	0.43	0.32	0.27	0.24	0.22	0.22	0.23	0.24	0.26	0.31	0.42	0.62	0.91	0.27
Jul	ka	0.79	0.58	0.37	0.28	0.24	0.21	0.19	0.19	0.19	0.20	0.23	0.27	0.35	0.54	0.87	0.23
	kc	0.79	0.58	0.37	0.28	0.24	0.21	0.19	0.19	0.19	0.19	0.22	0.27	0.35	0.53	0.87	0.23
Aug	ka		0.61	0.42	0.31	0.23	0.21	0.19	0.18	0.19	0.20	0.23	0.27	0.37	0.57		0.23
	kc		0.60	0.42	0.31	0.22	0.20	0.18	0.17	0.18	0.19	0.21	0.27	0.37	0.57		0.22
Sep	ka		0.87	0.54	0.37	0.30	0.26	0.23	0.23	0.23	0.25	0.29	0.36	0.51	0.81		0.28
	kc		0.87	0.52	0.36	0.29	0.25	0.23	0.22	0.22	0.24	0.28	0.34	0.48	0.81		0.27
Oct	ka		0.76	0.53	0.35	0.27	0.23	0.21	0.20	0.20	0.23	0.26	0.34	0.50	0.82		0.25
	kc		0.76	0.54	0.34	0.26	0.23	0.20	0.20	0.20	0.22	0.25	0.33	0.49	0.81		0.24
Nov	ka			0.71	0.44	0.34	0.27	0.25	0.22	0.24	0.26	0.32	0.42	0.69	0.76		0.29
	kc			0.70	0.42	0.31	0.26	0.24	0.21	0.22	0.23	0.27	0.39	0.64			0.27
Dec	ka			0.77	0.48	0.35	0.29	0.25	0.24	0.26	0.26	0.29	0.40	0.64	0.80		0.29
	kc			0.75	0.45	0.34	0.26	0.23	0.22	0.20	0.21	0.24	0.36	0.61			0.25
Jan' 93	ka			0.76	0.66	0.42	0.34	0.31	0.28	0.30	0.31	0.35	0.41	0.53	0.69		0.34
	kc				0.59	0.32	0.25	0.22	0.20	0.20	0.20	0.22	0.26	0.35	0.62		0.23
Feb	ka			0.68	0.48	0.33	0.28	0.25	0.22	0.21	0.22	0.27	0.28	0.37	0.53	0.78	0.26
	kc			0.67	0.45	0.30	0.26	0.22	0.18	0.17	0.17	0.20	0.22	0.31	0.49	0.78	0.22
Mar	ka			0.78	0.53	0.39	0.30	0.26	0.23	0.24	0.26	0.29	0.34	0.43	0.58	0.86	0.29
	kc			0.79	0.54	0.39	0.30	0.26	0.23	0.23	0.24	0.26	0.31	0.40	0.57	0.86	0.28
Apr	ka			0.68	0.43	0.52	0.28	0.27	0.27	0.24	0.30	0.33	0.38	0.47	0.60	0.78	0.32
	kc			0.65	0.43	0.31	0.22	0.20	0.20	0.18	0.20	0.23	0.30	0.30	0.53	0.72	0.25
May	ka		0.86	0.61	0.39	0.33	0.31	0.35	0.32	0.34	0.48	0.50	0.49	0.58	0.68	0.86	0.39
	kc		0.86	0.60	0.31	0.21	0.16	0.16	0.15	0.14	0.14	0.18	0.22	0.32	0.56	0.91	0.29
Summer	ka	0.79	0.65	0.43	0.31	0.25	0.22	0.20	0.20	0.20	0.21	0.24	0.29	0.39	0.60	0.88	0.25
	kc	0.77	0.63	0.41	0.30	0.24	0.21	0.19	0.19	0.19	0.20	0.23	0.28	0.38	0.59	0.87	0.23
Autumn	ka		0.82	0.64	0.40	0.31	0.25	0.23	0.22	0.22	0.24	0.28	0.38	0.59	0.83		0.27
	kc		0.82	0.61	0.39	0.30	0.25	0.22	0.21	0.21	0.23	0.26	0.36	0.56	0.83		0.26
Winter	ka			0.75	0.57	0.39	0.33	0.28	0.25	0.27	0.28	0.32	0.37	0.49	0.64	0.83	0.31
	kc			0.73	0.52	0.33	0.26	0.23	0.20	0.19	0.20	0.22	0.25	0.36	0.58	0.82	0.24
Spring	ka	0.77	0.76	0.59	0.39	0.39	0.27	0.26	0.26	0.25	0.30	0.33	0.37	0.46	0.62	0.88	0.31
	kc	0.80	0.75	0.55	0.35	0.29	0.23	0.21	0.21	0.21	0.22	0.24	0.30	0.40	0.59	0.83	0.27
Year	ka	0.78	0.71	0.58	0.42	0.33	0.27	0.24	0.23	0.23	0.25	0.29	0.35	0.49	0.66	0.87	0.28
	kc	0.79	0.70	0.54	0.38	0.28	0.24	0.21	0.20	0.20	0.21	0.24	0.30	0.43	0.64	0.85	0.25

thediffusesolarradiationmeasuredinbothallsky(D_a) and cloudless (D_c) sky conditions for investigating to what extend the clouds affect the values of diffuse solar radiation. The following conclusions may be deduced from this table:

(*i*) The same behaviours are generally observed for the variations of hourly and daily totals (monthly and seasonal averages) of diffuse solar radiation in all sky (D_{ah}, D_{ad}) and cloudless sky conditions (D_{ch}, D_{cd}). However, the measured values of D_{ch} and D_{cd} were smaller than those of D_{ah} and D_{ad}, indicating clearly the influence of clouds in increasing the diffuse solar radiation.

(*ii*) The average value of D_{ch} over the whole measurement period is maximum at midday hours (11-13 LAT). It has the value 0.65 MJ m^{-2} ranging from 0.83 MJ m^{-2} in June to 0.46 MJm^{-2} in December, while it is minimum in the early morning (Sunrise-7 LAT) and late afternoon (17-Sunset LAT) being in some months in the order of the instrument offset.

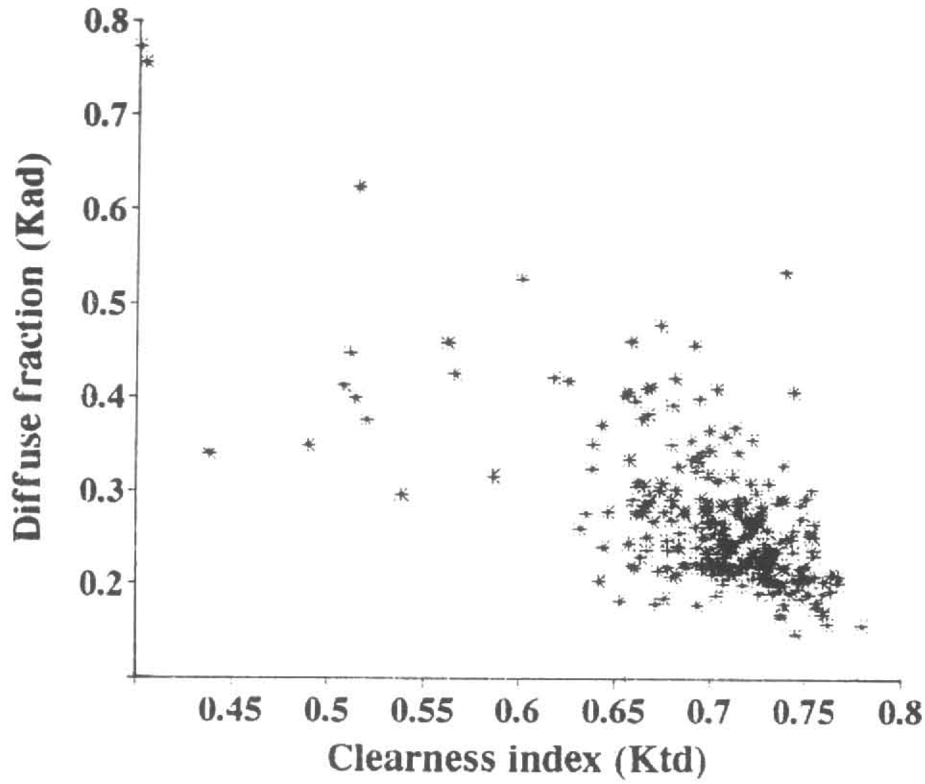

Fig. 4. Relation between daily values of diffuse fraction and clearness index

(*iii*) The monthly and seasonal average values of D_{cd} were maximum in May (7.37 MJ m^{-2}) and during the spring (7.66 MJ m^{-2}), while it is minimum in December (3.81 MJ m^{-2}) and during the winter (4.32 MJ m^{-2}). Its average value for the year is 5.95 MJ m^{-2}.

(*iv*) In average the effect of clouds is not large because thin and small amount of clouds in some months offset the effect of thick and large amounts in the other ones.

4.3. *Characteristics of diffuse fraction (k) of global solar radiation*

The diffuse fraction is defined as the ratio between the diffuse solar radiation and the global solar radiation, both received on a horizontal surface. Its diurnal and seasonal variations are presented and discussed in the following sections.

4.3.1. *All sky conditions measurements* (k_a)

(a) *Hourly variation of diffuse fraction* (k_{ah})

Table 5 summarizes the results of hourly variation of diffuse fraction from sunrise to sunset through the period from June 1992 to May 1993. k_{ah} decreases from sunrise till midday and then increases again towards sunset. Accordingly maximum values were listed for early morning (sunrise - 7 LAT) and late afternoon (17-sunset LAT). The average values over the whole period are in the ranges (0.58-0.78) and (0.66-0.87) in the early morning and late afternoon, respectively. Minimum values are obtained at midday hours (11-13 LAT) with an average value of 0.23. This behaviour is expected in terms of the higher attenuation of the direct solar component of global radiation in the early morning and late afternoon than in the noon hours, which is accompanied with decrease in G_{ah} values and an increase in D_{ah} ones.

(b) *Variation of daily averages of diffuse fraction* (k_{ad})

The variation of k_{ad} is shown in Fig. 3. Its value fluctuates obviously from day to day corresponding to the fluctuations of G_{ad} and D_{ad} discussed in sections 4.1 (b) and 4.2 (b). It ranges from 0.14 (25 Feb) to 0.9 (7 Jan) and is characterized with remarkable fluctuations in the day numbers from 326 to 172, in which k_{ad} value tends to be higher than in the other days of the measurement period. This is evident considering the instability of the atmosphere in these days with respect to water content, dust and clouds, which have also somewhat higher values in these days, as mentioned above. The average values

TABLE 6

Comparison between the yearly average of daily totals of global solar radiation (G) falling in horizontal surface in all sky conditions at different locations in Egypt

S.No.	Location	Global Solar radiation ($MJ\ m^{-2}$)
1.	Qena	22.6404
2.	Matru	19.89
3.	Tahrir	19.0584
4.	Cairo	23.0184
5.	Kharaga	23.0976
6.	Aswan	23.0976

of k_{ad} for each month and season in the measurement period are also given in the Table5. The maximum values were observed in May (0.39) as well as in winter and spring (0.31), while the minimum ones were recorded in July & August (0.23) and during the summer (0.25). In general the cloudiness is the main reason of this behaviour. This is indicated with the very high correlation found between k_{ad} and clouds amount (correlation coefficient =0.95). The influence of other affecting parameters such as aerosols may be more effective in the cloudless days. The average value of k_{ad} over the whole period is equal to 0.28, indicating the low degree of cloudiness in Qena, which gives more support to the high abundance of solar energy in this region.

(c) *Relation between* (k_{ad}) *and clearness index* (k_{td})

The clearness index is defined as the ratio of global solar radiation at the earth's surface (G_a) to extraterrestrial solar radiation (G_o) received on a horizontal surface. It refers to the availability of the solar radiation at the ground and indicates the influence of the atmospheric constituents such as water vapor, dust and clouds on it. So, high values of k_{td} are accompanied with low k_{ad}. The relation between k_{ad} and k_{td} is represented graphically in the scatter plot in Fig. 4 for all the daily measurements in all sky conditions. The figure shows that:

(*i*) The most of the values of diffuse fraction are at the right lower part of the plot (low k_{ad} and high k_{td}) giving further evidence to the high availability of incoming solar radiation during the most of the year in Qena.

(*ii*) For any value of clearness index k_{td}, there are many values of diffuse fraction k_{ad}, which means that k_{ad} depends on other parameters in addition to k_{td}. The most important parameter is the sun elevation, which plays an active part in this consideration. This conclusion seems to be more clear in view of the not very high correlation found between k_{ad} and k_{td} (correlation coefficient = -0.69).

4.3.2. *Comparison between the diffuse fraction in all* (k_a) *and cloudless* (k_c) *sky conditions*

In view of Table 5 and from the above discussions on the effect of clouds on both *D* and *G*, we can show that the behaviour of diffuse fraction in cloudless sky conditions (k_c) has the same generally patterns as in all sky conditions (k_a), but with lower values owing to the elimination of clouds effect. Table 5 summarizes the results of k_c through the measurement period. The maximum values of average k_c were observed in March and May (0.28) and during the spring (0.27), while the minimum ones were recorded in August (0.22) and during the summer (0.23). Considering that the main affecting parameters on k_c are the water vapour and the suspended dust particles, the above variation is possible in view of the dusty khamaseen wind blowing in the spring months and leading to high concentration of aerosols.

5. Conclusions

Based on the measurments of global and diffuse solar radiation and calculated diffuse fraction in the period from June 1992 to May 1993, the following conclusions can be deduced :

(*i*) The Qena region receives a considerable quantity of solar energy. 93% of the days through the year have values of global solar radiation in the high range from 15-35 $MJ\ m^{-2}$, while 91.6% of the days have diffuse solar radiation in the low range from 2 to 10 $MJ\ m^{-2}$. Average values of G_{ad}, D_{ad} and k_{ad} over the whole measurement period are 22.64 $MJ\ m^{-2}$, 6.21 $MJ\ m^{-2}$ and 0.28, respectively.

(*ii*) High values of G and small values of *D* and *k* were observed in cloudless sky conditions in comparison with those recorded under all sky conditions, reflecting the effect of clouds in depleting the incoming global solar radiation and in increasing its diffuse component. The reduction of global solar radiation by clouds represents a small percentage (4.6%), which refers to the low degree of cloudiness in the study region (1 octa in average over the year).

(*iii*) The relation between the diffuse fraction k_{ad} and clearness index k_{td} shows that the most results lie in the region of the high clearness index and low diffuse fraction indicating the availability of high incoming solar radiation during the most part of the year.

(*iv*) Considerable fluctuations of the different solar radiation components were observed in March, April, May and January owing to the large fluctuations in the atmospheric conditions in these months.

(*v*) The average value of daily totals of global solar radiation measured in Qena is comparable with that recorded by Meteorological Department of A.R. Egypt in different locations in Egypt (see Table 6).

(*vi*) The incoming solar energy at Qena is a significant source of renewable clean energy, which is sufficient to supply man's energy need and encourages us to use it for developing this region, a subject which should be considered in future.

References

Atwater, M.A. and Ball, J.T., 1981, "Effect of clouds on insolation models", *Solar Energy*, **27**, 37-44.

Kudish, A.T., Wolf, D. and Machlay, Y., 1983, "Solar radiation for Beer Sheva Israel", *Solar Energy*, **30**, 33-37.

Kuye, A. and Jagtap, S.S., 1992, "Analysis of solar radiation data for port harcourt, Nigeria", Solar Energy, **49**,2, 139-145.

Latimer, J.R. and MacDowall, J., 1971, "Radiation measurement, International field year for the great lakes", Technical Manual Series No.2, Meteorological Department of A.R.Egypt.

Moriarty, W.W., 1991, "Estimation of diffuse from measured global solar radiation", *Solar Eneregy*, **47**, 2, 75-82.

Morris, N., James, G.E. and William, D.B., 1982 ,"Understanding our atmospheric environment", W.H. Freeman Company, San Francisco.

Neuwirth, F., 1980, "The estmation of global and sky radiation in Austria", *Solar Energy*, **24**, 421-426.

World Meteôrological Organization (WMO), 1983,"Guide to Meteorological instruments and method of observation", Geneva, Switzerland