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The diffuse component of the global solar radiation at Qena / Egypt

SAYED. M. EL. SHAZLY

Deptt. of Physics, Faculty of Science, South Valley University, Qena/A.R. Egypt

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सार — क्वेना/मिश्र में क्षैतिजीय धरातलों पर सौर विकिरण के विसरित होने का आकलन किया गया है। दैनिक भू- मंडलीय क्षैतिजीय विकिरण (*G*) तथा उसके विसरित घटक (*D*) दोनों के परिमाणों के मापे गए मानों का उपयोग करते हुए लियु तथा जॉर्डन प्रकारों के विस्तृत प्रयोग द्वारा इन के मध्य संबंधों को विकसित करना आधारभूत कार्यपद्धति है। इस शोध-पत्र में.समाश्रयण मॉडलों के उपयोग से की गई विसरित विकिरण की गणना के परिणामों और अन्य परिचित लियु और जॉर्डन तरीकों से आकलित परिणामों का त्रुटि विश्लेषण किया गया हैं। विभिन्न संबंधों के सांख्यिकीय मूल्यांकन के आधार पर यह पाया गया है कि हमारे मॉडल विसरित विकिरण के सबसे अच्छे आकलन प्रदान करते हैं। इस शोध-पत्र में जलवायविक परिस्थितियों के प्रभाव पर भी विचार किया गया है।

ABSTRACT. Diffuse solar radiation on a horizontal surfaces is estimated at Qena / Egypt. The basic procedure is to develop relationships of the widespread use Liu & Jordan types between the daily global horizontal radiation (*G*) and its diffuse component (*D*) using measured values of these two quantities. An error analysis has been done for the results of diffuse radiation calculated using the regression models obtained in this paper and those estimated from other known ones of the Liu & Jordan type. According to statistical evaluation of the various relationships, it is seen that our models provide the best estimation of the diffuse radiation. Effect of climatic conditions was considered in the discussion.

Key words — Global solar radiation, Diffuse solar radiation, Liu & Jordan models, Effect of climatic conditions.

1. Introduction

The rapid increase in solar energy utilization in different fields of the science and engineering requires an improvement of the knowledge of characteristics of the solar radiation components (Moriarity, 1991). At present, global solar radiation incident on a horizontal surface is available in most meteorological stations, while data of diffuse radiation are rare and refer nearly always to limited periods. This situation has prompted the development of calculation procedures to provide estimation of the diffuse component (D) from usually measured values of the global radiation (G). These formulae are based on relationships between simultaneous values of D, G and extra- terrestrial radiation G_O on a horizontal surface. Numerous authors have dealt with investigations of this type of models, referred as Liu- Jordan models, proposing different methods and relationships (*e.g.* Neuwirth 1980, Barbaro *et al.* 1981, Moriarity 1991). Most of these relationships were developed to satisfy a particular local need. However, the overall forms of these models may be universal so that the user need only to verify and revise the numerical values of constants and coefficients for a particular location and time period.

Against this background we aim to evaluate selected known models, which either make some claim to generality or may be of general application. Also we develop our own regression models to estimate the diffuse radiation based on insolation measurements made at Qena /Egypt through the period, June 1992 - May 1994.

2. Experimental data

Kipp and Zonen precision pyranometer (Model CM 6B) was used to measure the global solar radiation G, another similar one, fitted with a shadow band of radius (r) 620 mm and width (w) 60 mm, constructed by the author following Kipp and Zonen rules, has been used to measure the diffuse component D. Both pyranometers were conjucted to two channels solar integrator (Kipp and Zonen model cc 12) to give the daily total values of both G and D in W m^{-2}. This type of pyranometers meet the majority of the requirements set for class I radiation sensor by the World Meteorological Organization (WMO 1983). According to the calibration certificate of the manufacturers, the sensitivity of the instruments is 11.66 x 10-6 V per Wm^{-2} with no load (± 0.5 % at 20° and 500 W m^{-2}). It has a directional error <20 Wm^{-2} at 1000 Wm^{-2} and a non- linearity <1.5%

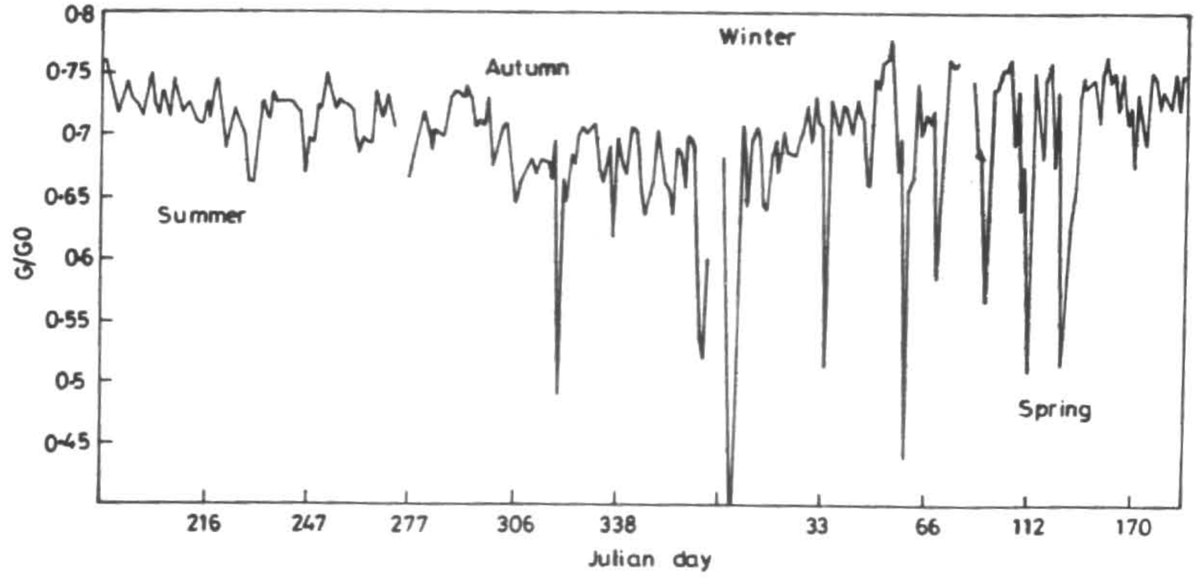

Fig.1. Variation of the clearness index G/G_o through the year at Qena/Egypt

TABLE 1
Regressions between K_d,K and K_T for different time periods data, evaluated for Qena/Egypt

Period		Form of regression	RMSE	MBE	MAE
Monthly Average	All day	K_d=0.937-0.946K_T	0.0284	-0	0.025
		K=0.338-0.213K_T	0.0197	0	0.017
	Cloudless	K_d=0.670-0.586K_T	0.0289	-0	0.022
		K= 0.298.0.167K_T	0.0180	-0	0.016
Summer	All days	Kd=-2.144+8.022K_T-6.522K_T^2	0.0325	0	0.026
		K = -2.347+7.764K_T.-5.909K_T 2	0.0234	0	0.020
	Cloudless	K_d=-0.970-1.009 K_T	0.0311	0	0.026
		K = -2.606+ 0.244K_T-6.082K_T^2	0.0223	0	0.019
Autumn	All days	K_d=0.965-1.016K_T	0.0560	-0	0.040
		K=0.406-0.326K_T	0.0350	-0	0.026
	Cloudless	K_d=-7.771 + 24.022K_T-17.916K_T^2	0.0414	-0	0.030
		K=5.935+17.984K_T-13.2001K_T^2	0.0281	-0	0.021
Winter	All days	K_d=-0.429+20.460K_T-83.201K_T^2 +121.941K_T^3-61.162K_T^4	0.0711	0	0.053
		K=-1.535+17.070K_T-55.478K_T^2 +74.635K_T 3-36.000K_T^4	0.0450	0	0.035
	Cloudless	K_d=0.987-1.039 K_T	0.0678	-0	0.051
		K=0.537-0.509K_T	0.0442	-0	0.036
Spring	All days	K_d=-1.046+5.285K_T-4.755K_T^2	0.0672	-0	0.045
		K=-1.260+4.906K_T-3.970K_T^2	0.0478	-0	0.032
	Cloudless	K_d=-12.459+36.296K_T-25.836K_T^2	0.0442	-0	0.037
		K=-9.203+26.539K_T-18.718K_T^2	0.0321	0	0.027
The whole period	All days	K_d=3.117-11.388K_T+16.354K_T^2-8.422K_T^3	0.0612	-0	0.045
		K = 0.560-1.701 K_T+ 3.101 K_T^2 -2.043K_T^3	0.0407	0	0.031
	Cloudless	K_d=-2.614+8.918K_T-6.864K_T^2	0.0463	0	0.035
		K =-2.383+7.572K_T-5.574K_T^2	0.0327	0	0.025

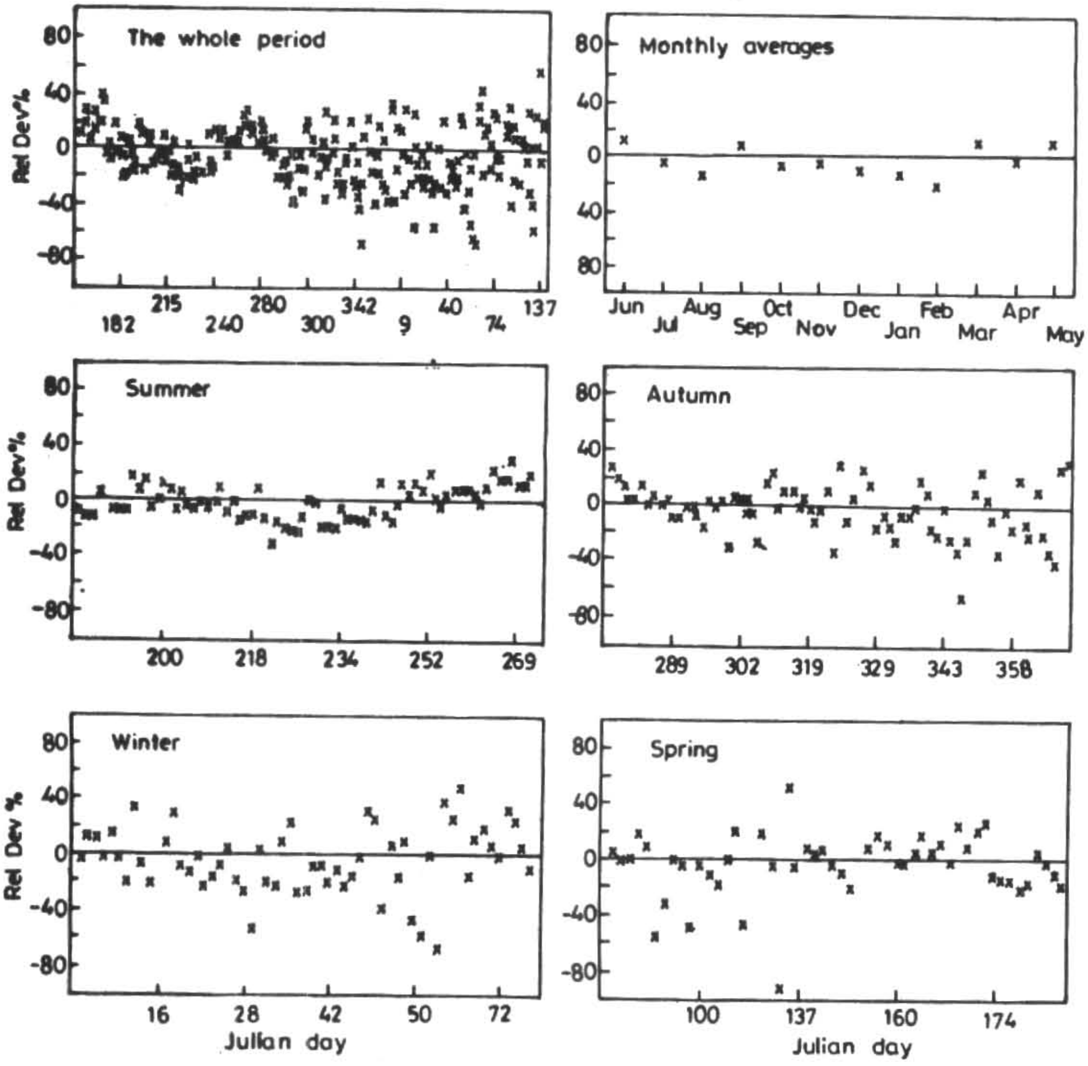

Fig.2. Relative deviation of calculated diffuse radiation from experimental one for all days at Qena/Egypt

(1000 W m^{-2}), while the inaccuracy of the solar integrator lie within 0.2% = 1 digit.

The observing site (Latitude 26°.10, Longitude 32°.43 and height above the sea level = 78m) affords optimum exposure with no obstructions extending beyond 3° above the plane of the sensors elements. The setting of the shadow band was checked twice daily making sure of the centering of the sun image on the sensor of the pyranometer all day around. Every few days the band position is adjusted to the declination of the sun. The measured values of *D* were multiplied by a correction factor *f* of values range from 1 to 1.14, calculated daily to compensate the small part of the diffuse sky radiation, which is obstructed by the shadow band. This value is determined by Latimer and Mac Dowall, (1971) as:

$$f = 1 / (1 - F/D) \tag{1}$$

in which, assuming the isotropic distribution of sky radiance,

$$F/D = (2\,w/\,\pi\,r)\mathrm{Cos}\,3\delta\ \ (\mathrm{Sin}\,\phi\ \mathrm{Sin}\,\delta\ H_O + \mathrm{Cos}\,\phi\ \mathrm{Cos}\,\delta\ \mathrm{Sin}\,H') \tag{2}$$

where, δ is the solar declination, φ is the station latitude and *H′* is the hour angle of the sun at sunset. Daily values of the extra-terrestrial radiation G_O are computed with the aid of conventional astronomical formula (Klein 1977) using a value of 1376 W m^{-2} for the solar constant as:

$$G_O = (24/\pi)I_O\,[\mathrm{Cos}\,\varphi\ \mathrm{Cos}\,\delta\ \mathrm{Sin}\,H + (H \times \pi/180)\ \mathrm{Sin}\,\phi\ \mathrm{Sin}\,\delta] \tag{3}$$

There was no evidence of errors in the measured radiation records except for little occasions near sunrise and sunset when *D* exceeded *G*. In these instances the observations were rejected.

TABLE 2

Comparison of statistical attributes of various regression methods for determination of diffuse radiation D at Qena/Egypt

Model		Monthly average		Summer		Autumn		Winter		Spring		Whole period	
		All days	Cloudless	All days	Cloud-less	All days	Cloud-less	All days	Cloud-less	All days	Cloud-less	All days	Cloud-less
D exp		1737	1593	1883	1820	1379	1375	1396	1347	2249	2003	1671	1617
	Dcal	1752	1595	1871	1828	1371	1370	1388	1331	2244	2000	1655	1610
This work [K_d&K_T]	RMSE	193	188	238	230	273	267	363	377	524	350	374	290
	MBE	-15	-2	-8	-8	8	5	10	15	352	3	16	7
	MAE	174	144	196	196	210	198	269	275	5	294	289	222
	Dcal	1724	1591	1871	1828	1372	1370	1380	1331	2244	2000	1658	1810
This work	RMSE	195	183	238	228	282	287	381	378	525	348	374	290
[K_d&K_T]	MBE	13	2	-8	-8	7	5	9	15	5	4	16	7
	MAE	160	148	196	194	212	198	271	275	352	292	288	222
	Dcal	1723	1511	1753	1722	1511	1452	1452	1325	1882	1617	1618	1536
	RMSE	280	258	275	287	297	234	443	396	747	544	452	346
OH	MBE	14	82	111	99	-132	-77	-58	22	387	388	54	81
	MAE	221	209	215	207	220	181	330	296	599	470	320	259
	Dcal	1588	1411	1646	1622	1403	1337	1383	1255	1837	1601	1532	1451
	RMSE	294	293	324	305	280	224	451	398	783	551	471	357
EKDH	MBE	150	182	217	198	-24	38	13	82	411	402	139	165
	MAE	229	207	245	230	197	170	317	269	615	487	322	259
	Dcal	1367	1274	1491	1480	1372	1162	1130	1098	1558	1469	1309	1299
	RMSE	441	384	439	405	317	300	480	461	884	650	536	441
LJ	MBE	370	319	372	341	207	213	226	249	691	534	363	318
	MAE	370	319	374	343	242	238	319	296	717	558	391	339
	Dcal	1335	1208	1408	1390	1166	1136	1117	1051	1497	1349	1288	1231
	RMSE	478	453	509	482	323	322	478	490	942	753	576	502
Page	MBE	402	385	455	430	211	239	279	295	752	654	403	396
	MAE	402	385	457	431	261	266	345	331	781	667	439	413
	Dcal	3951	3798	4478	4465	3203	3244	3319	3266	4761	4650	3888	3908
	RMSE	2248	2248	2840	2889	1847	1888	1980	1982	2579	2872	2381	2348
CPR	MBE	-2214	-2203	-2613	-2844	-1824	-1889	-1923	-1940	-2513	-2847	-2214	-2289
	MAE	2214	2203	2613	2844	1824	1889	1923	1940	2513	2847	2214	2289

3. Methodology

To estimate D at different locations, the regressions after Liu - Jordan proved useful. It is based on the fact that analysis of G and D measurements reveals the ratios $D/G = K_d$ and $D/G_O = K$ to be functions of the clearness index $K_T = G/G_O$. Accordingly, D can be estimated by $D = G\,f(K_T)$ or $D = G_O\,f(K_T)$. We try in this paper to readjust previous relationships of this type established by other authors using our own measured data of daily totals values of G and D in the study region. The results were classified into two groups: all days and cloudless days measurements. Within each group, regression models were derived for different time periods namely: each season of the year, monthly averages and over the whole period. The following formulae have been used:

$$Y = a_0 + a_1 x \tag{4}$$

$$Y = a_0 + a_1 x + a_2 x^2 \tag{5}$$

$$Y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 \tag{6}$$

$$Y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 \tag{7}$$

The coefficients a_i of every equation were determined using the known least square method. Their performance is indicated by calculating the mean bias error (MBE) and the root mean square error (RMSE), which measure systematic and non systematic errors, respectively. Since the MBE cancel significant positive and negative biases, the mean absolute error (MAE) was also computed. The following equations have been used to calculate these errors :

$$\mathrm{RMSE} = [\Sigma\,(Y\mathrm{exp} - Y\mathrm{cal})^2 / N]0.5 \tag{8}$$

$$\mathrm{MBE} = [\Sigma(Y\mathrm{exp} - Y\mathrm{cal}\,) / N] \tag{9}$$

$$\mathrm{MAE} = [\Sigma\,(Y\mathrm{exp} - Y\mathrm{cal}) / N] \tag{10}$$

Model performance as defined by these statistics was determined for each time period for both K_d and K. In general, each of the above eqns. (4 - 7) exhibits nearly a good correlation. Regression model of lower order; simple values of coefficients (with small standard errors); and smallest values of RMSE and MBE or MAE were considered as best one to be used for determining D.

4. Results and discussion

Table 1 summarizes the best models obtained for K_d and K against K_T at different time period for both all and cloudless days. From this table one can see the following:

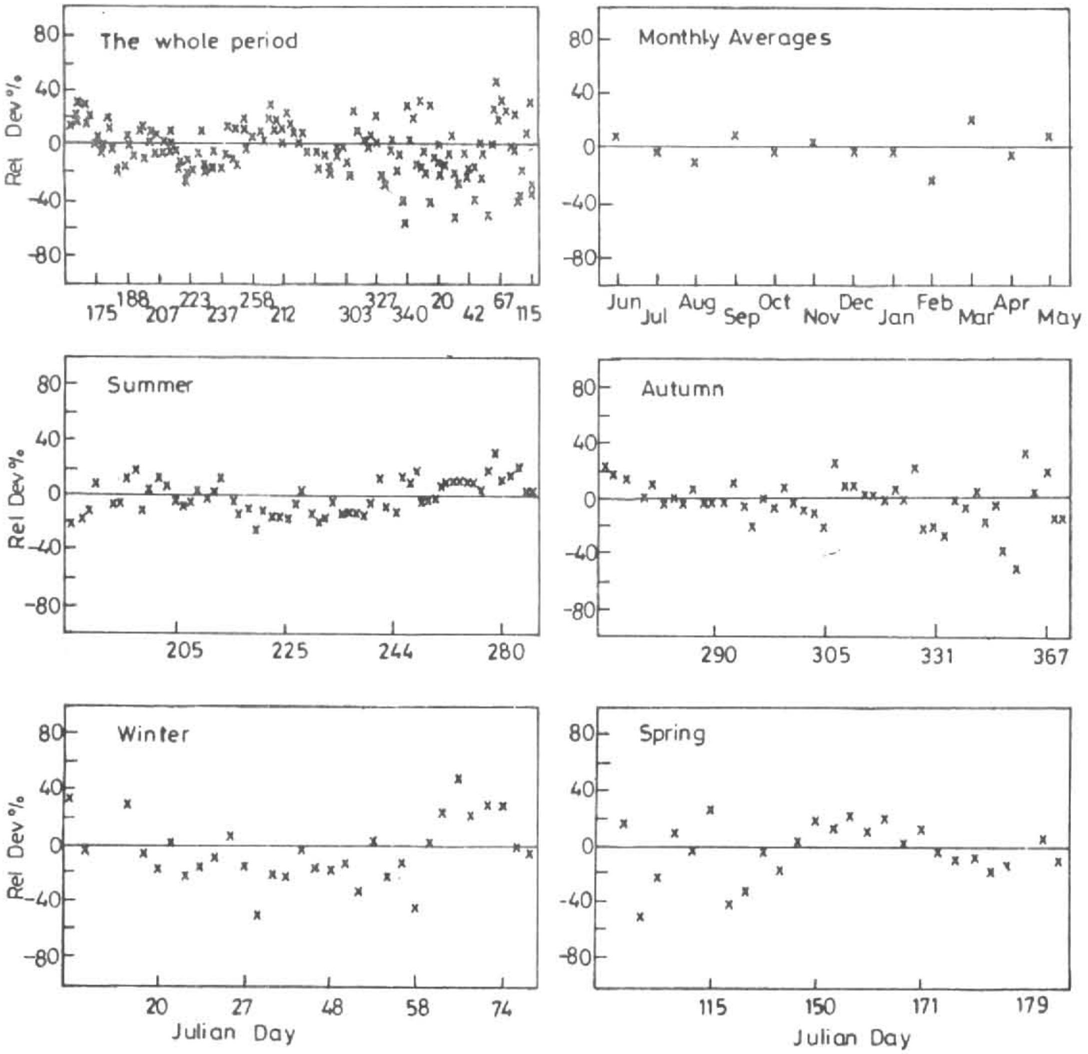

Fig. 3. Relative deviation of calculated diffuse radiation from experimental one for cloudless days at Qena / Egypt

(*i*) The need for polynomial regression models of the third and higher order is not very obvious.

(*ii*) No significant differences appear between the performance of the two types of regression. Both lead to quasi the same values of *D* (see Table 2).

(*iii*) Smaller values of errors were found at cloudless days - in comparison to all days - measurements, due to the absence of the complex effect of clouds at these days.

(*iv*) Both regression forms provide best estimates for monthly averages data, while worst estimates were obtained for winter and spring ones. This is probably due to the maximum of both cloud cover and weather disturbances in these seasons. Average amounts of clouds in octas found in winter and spring were 1.61 and 1.49 corresponding to 0.11 and 0.75 in summer and autumn respectively. Most of them were fairly transparent cirrus except in winter and some days in spring, in which less transparent As and St types were observed. Also spring months are characterized with high fluctuation of aerosols as dusty storms blow in some days in these months. This explanation seems to be very logical in view of the fluctuation of the clearness index G/G_O in both winter and spring as shown in Fig.1, which shows its variation through the year over the study region. Because the dependence of G/G_O on solar altitude is considerably reduced, it shows distinctly the effect of the atmospheric components on the attenuation of the incoming solar radiation.

(*v*) The entries in Table 1 indicate also a discernible seasonal dependence which is caused by seasonal changes in factor that affect the diffuse component, namely cloudiness and air quality (turbidity, moisture content) (Nagaraja Rao *et al.* 1984). Distribution of Linke turbidity factor, which indicates the water vapour and aerosol contents, through different months and seasons of the year at Qena / Egypt has been discussed by El - Shazly (1996).

To verify whether the obtained relationships allow a reliable estimate of diffuse radiation D, relative deviations in % of its calculated values from the measured ones for different periods are computed. The results are given in Figs. 2&3 for all days and cloudless days, respectively. It is clear that these regressions gave satisfying results in the most days of the year, especially for monthly average data. The most points lie in the range of relative deviation within ± 20% except in winter and spring, in which some of these points have relative deviation >+ 20%. Generally, the dispersion of points is relatively higher for all days measurements than for cloudless days.

For practical purpose it is also interesting to compare the errors established in determining D from applying our regression models with those arise from the frequently used relationships in the literature of Liu and Jordan types. The results are summarized in Table 2. The following equations were considered:

(1) Orgill and Hollands (1977) model [OH]

$$K_d = 1.557 - 1.84\ K_T \qquad (11)$$

(2) Erbs *et al.* (1982) model [EKDH]

$$K_d = 0.9551 - 0.1604K_T + 4.388K_T2$$

$$-16.638\ K_T3 + 12.336K_T4 \qquad (12)$$

(3) Liu and Jordan (1960) model [LJ]

$$K_d = 1.39 - 4.027K_T + 5.531K_T2 - 3.108K_T3 \qquad (13)$$

(4) Page (1961) model [Page]

$$K_d = 1.0 - 1.13\ K_T \qquad (14)$$

(5) Collares - Pereira and Rabl (1979) model [CPR]

$$K_d = 1.88 - 2.72K_T + 9.43K_T2 - 21.856K_T3$$

$$+14.648K_T4 \qquad (15)$$

According to statistical quotations on the quality of the different regressions summarized in Table 2, it is seen that:

(*i*) All the five models behave simultaneously as our model in such way that they show better accuracy for monthly averages data in comparison to winter and spring data. Also they confirm better in cloudless days than in all days measurements.

(*ii*) As expected our models provided the best estimates of D, following by OH and EKDH ones.

(*iii*) Results of OH and EKDH are very similar.

(*iv*) CPR model did not perform as well as the other four models for all time periods data in both all and cloudless days. This conclusion has also been found by Davies and Mckay, 1989 for data from different countries.

5. Conclusions

(*i*) Simple regression models of Liu and Jordan type have been developed for the estimation of the daily diffuse solar radiation at Qena / Egypt, based on measurements of G and D made during 1992 - 1994.

(*ii*) Statistical treatment of the results indicates the high performance of these models in comparison with some well known ones of the same type.

(*iii*) The models provide the best performance for monthly averages data and the worst one for spring and winter. This may be due to the weather disturbances (cloud cover, turbidity and water vapour) characterize the study region in these seasons.

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