Empirical Correlation Of Daily Global Solar Radiation With Meteorological Parameters For Qena (Upper Egypt)

Emad Ali Ahmed
Physics department, faculty of sciences
South Valley University
Qena 83523, Egypt
emad.amer@sci.svu.edu.eg

M. El-Nouby Adam
Quality Assurance Unit (ALI), King Saud University, Riyadh 11491, Saudi Arabia
Faculty of Science (Physics Department), South Valley University, Qena 83523, gypt
mnadam@SVU.edu.eg

***Abstract*—This work describes the behaviors of daily global solar radiation (Gd) as a function of some meteorological parameters such as the bright sunshine (S), relative humidity (RH), air temperature (Ta), wind speed (Ws), sea level pressure (PMSL) and water vapor pressure (V) through the study period (2001-2002) over Qena, Egypt. Multiple linear regression models were developed between the daily values of the global solar radiation and these meteorological parameters during this period. The best values of multiple correlation (R) and standard error of estimation (SE) were 0.913 and 0.025 respectively. This correlation equation is given as:**

$$\frac{G_d}{G_0} = 0.428 + 0.117\frac{S}{S_0} + 0.0262S - 0.003R_H - 0.003T_a + 0.003W_S + 2.192P$$

A good agreement was observed between the measured and the predicted values of our models (correlation coefficients was more than 0.98).

Keywords*— *solar energy; global solar radiation; meteorological parameters.

I. INTRODUCTION

Qena (26^0 17`, 32$^0$ 10`, 96 m asl) is located in the south part of Egypt. Climatically, it lies within the subtropical region characterized by hot, dry and calm weather with low cloudiness (80 % of the days of the year are cloudless) and it is a city of abundant solar radiation along most of the months of the year which gives us the hope to use it in the future as energy source to solve the energy demand problem [1-3].

It is not a rare occurrence that solar radiation data are needed for sites where no measuring instrument is installed. Typical is the case of mapping the solar climate for a large region starting from a measured solar radiation database relative to a few isolated stations. A similar problem arises when instruments have been working for a very short time, such as one year or less, so that reliable frequency distributions or even statistical averages are not available to designers or researchers [4].

Global solar radiation data is essential for the study and design of the economic viability of systems that use solar energy. The global solar radiation data required for solar energy use are in the form of; diurnal variation, monthly mean daily values, frequency distribution of number of consecutive days in each calendar month, with insulation below or above a certain threshold and frequency distribution of monthly mean and annual mean values [5]. There are, of course, other uses of such information, including forecasts of evaporation from dams, agricultural potential and meteorological forecasting. In spite of the importance of global solar radiation data, few meteorological stations, especially in developing countries, measure accurately and continuously these data [6].

Thus, inquiries about the existence of relationships between global solar radiation and other available meteorological parameters (such as sunshine duration hours, air temperature, relative humidity etc) are very interesting. Trabea et al. (2000) [7] have described the mathematical expression of the various models, which discussed the empirical correlation of G_d with the meteorological parameters. The forms of some empirical models are given briefly below:

- Gophanthan (1988) [8] introduced a multiple linear regression equation of the form:

$$\frac{G_d}{G_0} = a + b\cos\varphi + ch + d\frac{S}{S_0} + eT_{max} + fR_H \qquad (1)$$

- The model for Bahrain is written as [9]:

$$\frac{G_d}{G_0} = a + b\frac{S}{S_0} + cT_{max} + dR_H \qquad (2)$$

and

$$\frac{G_d}{G_0} = a + b\frac{S}{S_0} + cT_{max} + dR_H + e\frac{1}{P} \qquad (3)$$

- Trabea et al. (2000) [7] models have the forms:

$$\frac{G_d}{G_0} = a + b\frac{S}{S_0} + cT_{max} + dV + eR_H + f\frac{1}{P} \qquad (4)$$

A multiple regression equation could be employed by Akpabio et al. (2004) [6] for the purpose of estimating global solar radiation within the rain forest climate zone. They used ten meteorological parameters. However, they started with one variable correlation to ten variable correlations. Akpabio et al. (2004) [6] concluded that the best empirical equation to estimate the global solar radiation of locations that have the same climate, latitude and altitude is;

$$G_d = -a + bG_0 + cT_a - d\theta + e\delta + fR_H + g\frac{S}{S_0} - iT_s + jE_v \quad (5)$$

Where h is the elevation of the location in kilometers above sea level, T_{max} is the maximum temperature, θ ratio of minimum to maximum temperatures, T_s is the soil temperature and E_v is the pan evaporimeter. The values of the coefficients a, b, c, d, e, f, g, j and i are different from model to another one.

This paper study the characteristics of the daily global solar radiation at Qena during the period of this study (2001-2002) and tried to investigate suite of empirical models used in the estimation of the daily global solar radiation from the meteorological parameters.

II. METHODOLOGY

The global solar radiation (G_d), bright sunshine (S), relative humidity (R_H), air temperature (T_a), wind speed (W_s), mean sea level pressure (P_{MSL}) and water vapor pressure (V) data reported in this paper were supplied by SVU-meteorological research station.

The estimated parameter such as extraterrestrial radiation, G_0 and the day length in hours S_0 obtained from the following equations [10].

$$G_0 = \frac{T}{\pi} I_{sc}\left[1 + 0.033\cos(2n\pi/365.24)\right]\cos\varphi\cos\delta(\sin H_0 - H_0\cos ws) \quad (6)$$

$$S_0 = \frac{2}{15}\cos^{-1}(-\tan\varphi\tan\delta) \quad (7)$$

Where:

T = length of day, 24 hours;

I_{sc} = solar constant, 1353 W/m^2;

n = Julian day number;

ϕ = latitude, 26.17^0;

H_0 = sunset hour angle;

δ = solar declination given by (Hulstrom and Imamura, 1979) [11]:

$$\delta = 23.45\sin\left[360^0(n + 284)/365\right] \quad (8)$$

III. RESULTS AND DISCUSSION

The data used in this work are arranged in graphs such as: daily global solar radiation, G_d and clearness index, G_d/G_0 (Fig.1), bright sunshine, S and the ratio of S/S_0 (Fig.2), relative humidity, R_H (Fig.3), air temperature, T_a (Fig.4), wind speed, W_s (Fig.5) and water vapor, V and the ratio of mean sea level pressure to V, P (Fig.6). The variation of each parameter through the period of the study was described. From these graphs the following can be briefly summarized:

A. With respect to G_d (Fig. 1)

It is clearly that the value of G_d varies from 32.7 MJm^{-2}/day (at the day number 157: June 6) to 10.5 MJm^{-2} /day (at the day number 93: April 3) in 2001. Also its value varies from 32.1 MJm^{-2}/day (at the day number 176: June 25) to 11.1 MJm^{-2}/day (at the day number 10: January 10) in 2002. According to the astronomical cycle of the earth, the sites situated outside the tropics in the northern hemisphere have the maximum and the minimum global solar radiation at the June solstice (June 20/21) and the December solstice (December 20/21), respectively [12]. The observed shift is due to the effect of the atmospheric conditions.

Add to, there is a remarkable variation from day to day. This fluctuation is also due to the vibration of the atmospheric conditions with respect to water content, dust and type and amount of clouds, which change from hour to hour and day to day (see the fluctuation of the clearness index in the same figure and the behaviors of S and S/S_0 in Fig. 2).

The variation of the monthly average of G_d is shown in table 1. The average values of Gd were from 30.6 MJm^{-2}/day in June to 14.0 MJm^{-2}/day in December with annual mean was equal to 23.2 MJm^{-2}/day in 2001 and 23.5 MJm^{-2}/day in 2002. This is due to the astronomical factor. However, the daily mean hours of the bright sunshine (S) at June was the maximum (12.6 hours) and at December was the minimum (9.7 hours).

B. With respect to R_H (Fig. 3)

The values of R_H change from 67.1% (at the day number 12: January 12, 2001) to 11.7% (at the day number 148: May 28, 2001) and there is a fluctuation of the values of the relative humidity from day to day.

Moreover the monthly average of the daily values of R_H is shown in table 1, in which, the maximum and minimum values were recorded at January (49.9%) and May (22.4%) respectively, with an annual mean values was equal to 34.5% in 2001 and 34.0% in 2002.

However Qena lies in south between the western and eastern desert, its climate is dray especially in summer [13].

C. With respect to Ta (Fig. 4)

The daily values of air temperature at Qena during the period of this study (2001, 2002) fluctuate from day to day. Its maximum and minimum values were 40.4 ^{0}C (at the day number 212: July 31, 2002) and 9.2 ^{0}C (at the day number 6: January 6, 2002).

Table 1 concludes the monthly average of Ta. These monthly average varied from 34.9 ^{0}C at August to 14.4 ^{0}C at January, with an annual mean values was equal to 25.8 ^{0}C in 2001 and 26.2 ^{0}C in 2002.

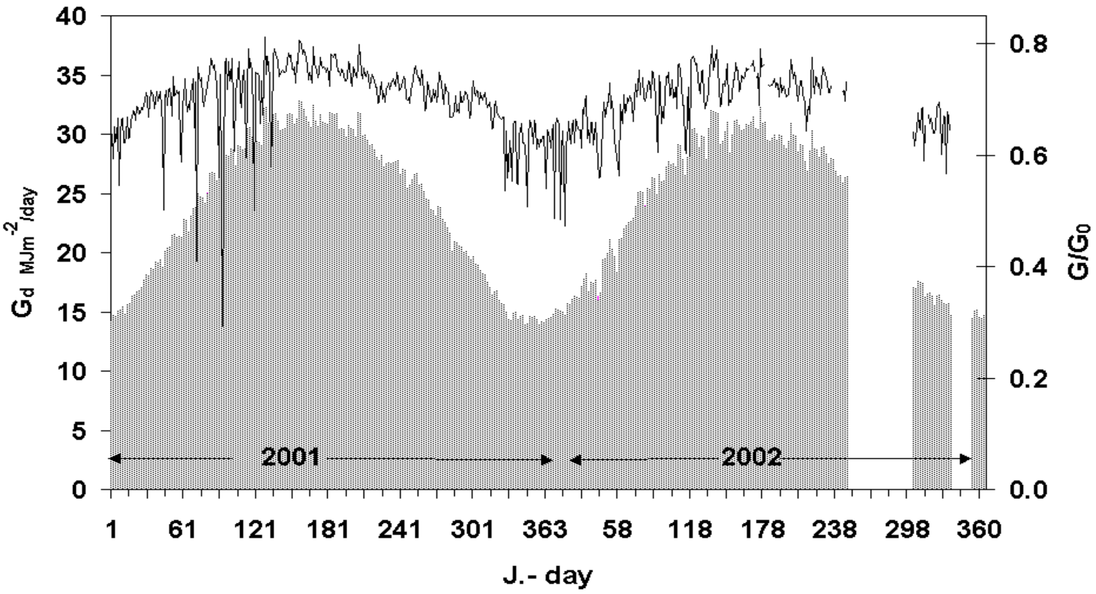

Fig1. *Daily variation of Gd and Gd/G0 at Qena during the study period (2001- 2002).*

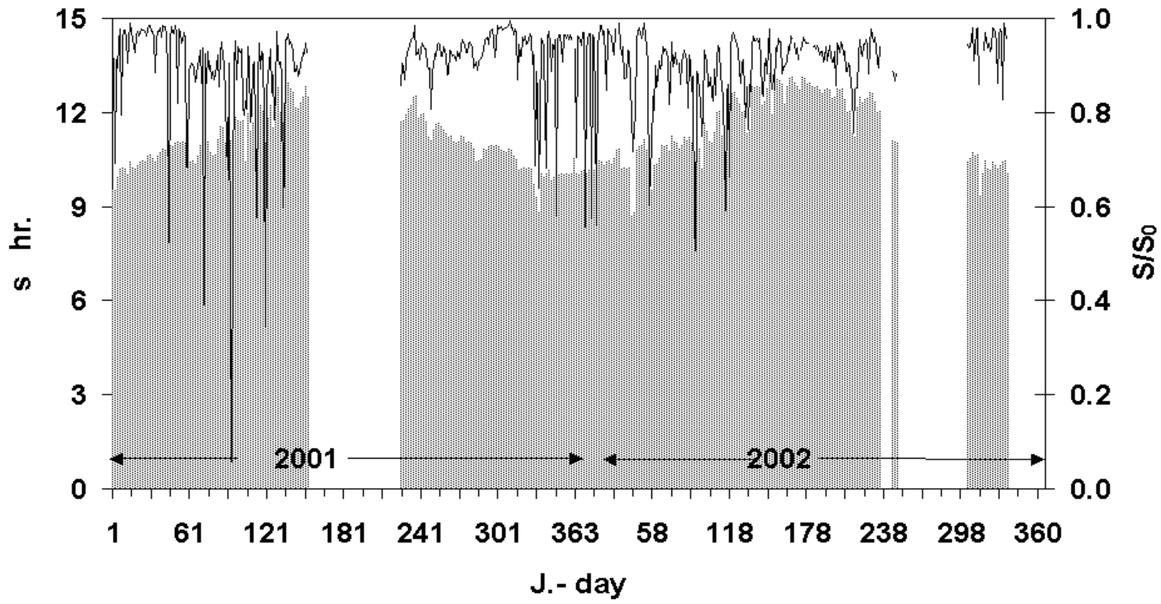

Fig 2. *Daily variation of S and S/S_0 at Qena during the study period (2001- 2002).*

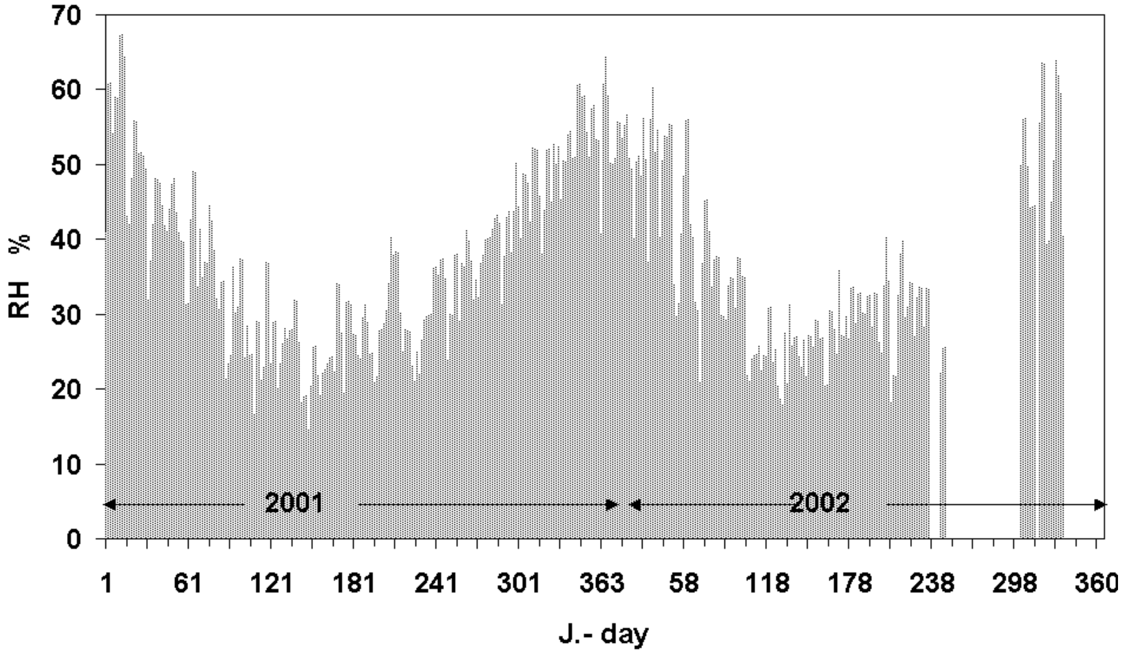

Fig 3. *Daily variation of R_H at Qena during the study period (2001- 2002).*

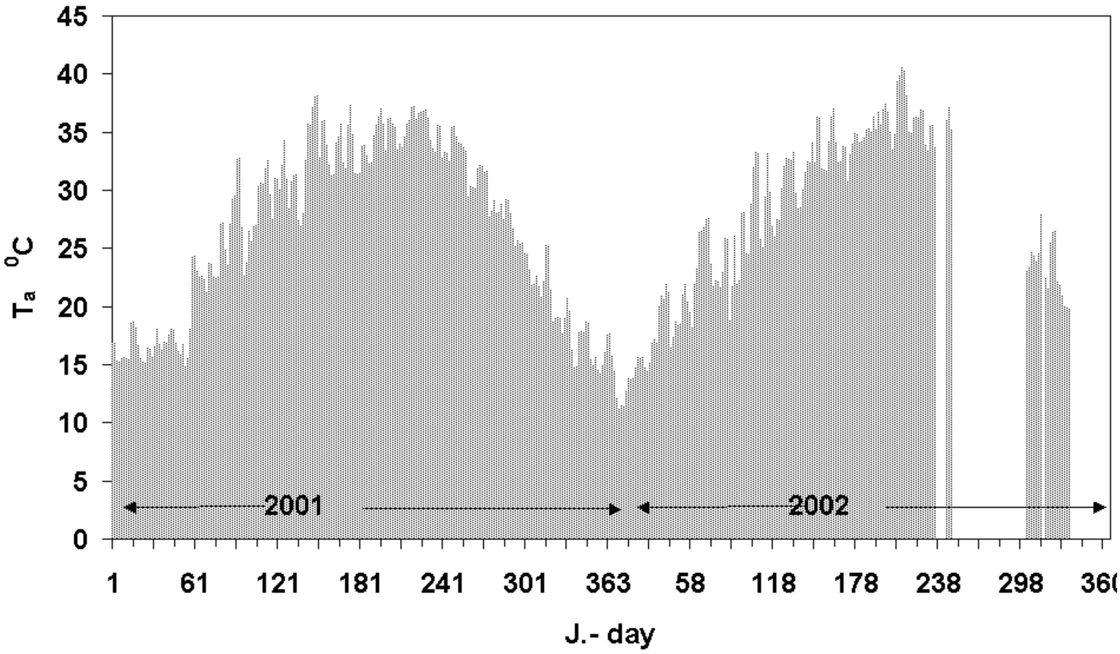

Fig 4. *Daily variation of Ta at Qena during the study period (2001- 2002).*

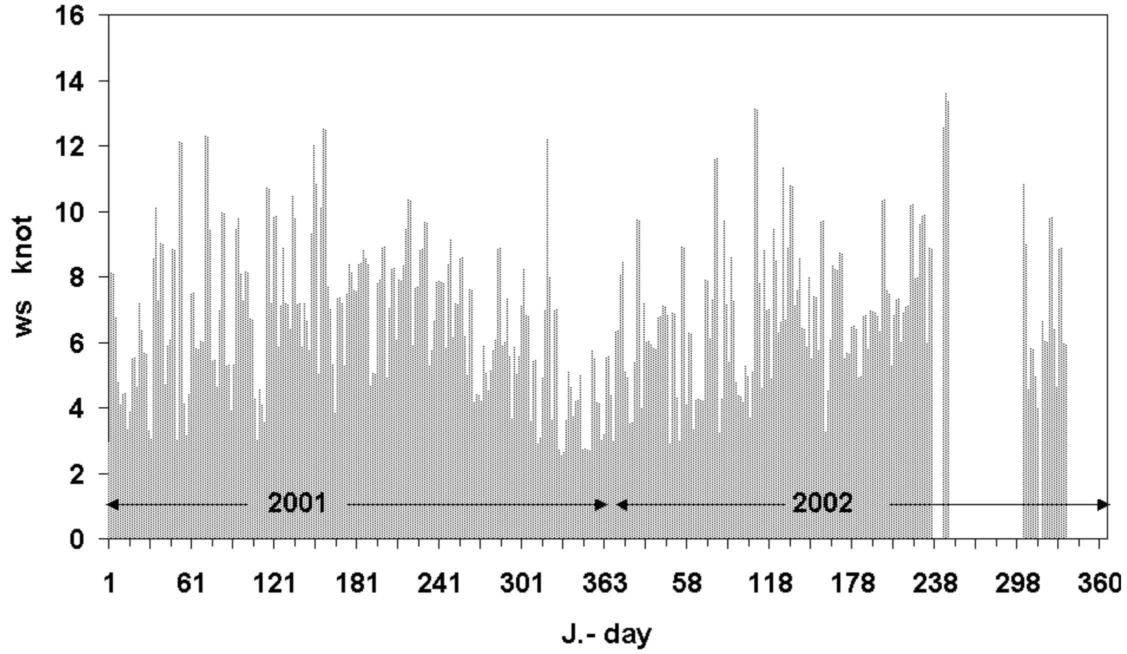

Fig 5. *Daily variation of Ws at Qena during the study period (2001- 2002).*

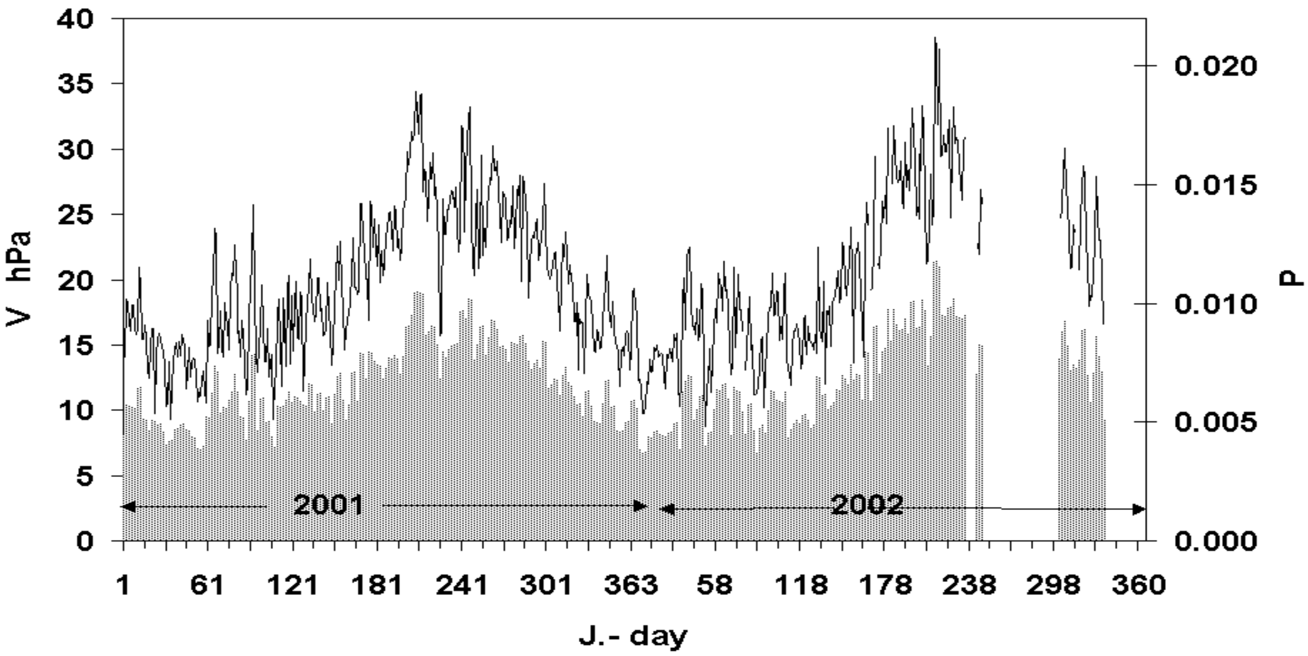

Fig 6. *Daily variation of V and P at Qena during the study period (2001- 2002).*

Table 1. Monthly mean of daily values of clearness index (G_d/G_0); global solar radiation (G_d); bright sunshine (S); air temperature (Ta); relative humidity (R_H); wind speed (WS); water vapor pressure (V) and air pressure at see level (PMSL) at Qena through the study period (2001-2002).

Month	G_d/G_0	G_d (MJm^{-2}/day)	S (hr.)	T_a (^0C)	RH %	WS (Knot)	V (hPa)	P_{MSL} (hPa)
Jan	0.643	15.2	09.8	14.4	49.9	4.3	08.2	1024.3
Feb	0.665	18.5	10.0	17.5	41.1	4.9	08.2	1015.8
Mar	0.699	23.1	10.2	23.1	33.4	5.2	09.3	1011.2
Apr	0.699	26.2	10.3	26.8	25.7	5.3	08.9	1015.6
May	0.740	29.5	11.9	30.7	22.4	6.7	09.7	1013.9
Jun	0.753	30.6	12.6	32.8	24.3	6.3	11.9	1011.6
Jul	0.739	29.6	12.4	34.8	27.4	6.2	14.9	1003.8
Aug	0.723	27.4	11.8	34.9	28.3	7.1	15.6	1010.8
Sep	0.717	26.0	11.0	33.8	27.3	9.0	14.0	1008.0
Oct	0.665	18.4	10.5	24.4	45.5	7.6	13.7	1017.5
Nov	0.659	16.0	10.0	21.4	47.2	4.6	11.9	1021.2
Dec	0.631	14.0	09.7	17.7	45.6	4.6	09.1	1029.0
Mean	**0.694**	**22.9**	**10.9**	**26.0**	**34.9**	**6.0**	**11.28**	**1015.2**

As mentioned in Trabea et al. (2000) [7], the high value of the monthly mean of Ta reflects the behavior of the subtropical region.

D. With respect to Ws (Fig. 5)

The values of Ws change from 13.5 knot (at the day number 246: September 3, 2002) to 1.8 knot (at the day number 16: January 16, 2002) and there is a fluctuation in its values from day to day.

The monthly average of Ws was calculated as given in Table 1. The maximum and minimum values were founded at September and January (9.0 and 4.3 knot respectively) with an annual mean value was equal to 5.4 knot in 2001 and 5.7 knot 2002.

At the region of this study the winds are light most of the year. This is agreeing with the previous work in the study area [13].

E. With respect to V (Fig. 6)

This figure shows the vibration of V and refers to its maximum and minimum values (21.3 hPa: at the day number 214, August 2, 2002 and 4.9 hPa: at the day number 49, February 20, 2002) through the period of this study.

The annual mean values were 11.0 hPa (2001) and 11.2 hPa (2002).

Finally, it is clear that:

The variation of daily values of G_d, S, T_a, V, and P has the same trend, but values of R_H have opposite trend.

The variation of G_d/G_0 and S/S_0 has the same trend and, approximately, has a similar trend of V and P.

The variation of Ws is not similar to G_d/G_0 or G_d but the important of this parameter is due to its effect in the aerosols of the atmosphere which effect on the global solar radiation. When the winds are light that may favour the accumulation of urban dust in the atmosphere. However, there are several reasons for airborne dirt in the atmosphere of Qena. The main source are: sands and soil from the western and eastern hills which overlook the city; dusty roads with incomplete garbage removal and the influence of man such as agriculture, automobiles and industry [13].

The various meteorological parameters shown in table 1 are all related to global solar radiation in varying degrees. In order not to overlook any particular parameters or group of parameters, multiple linear regression analysis of seven parameters (T_a, R_H, S/S_0, S, V, P and W_s) was employed to estimate G_d/G_o. The various linear regression analyses are as follows; one variable correlations, tow variable correlations, three variable correlations, four variable correlations, five variable correlations and six variable correlations. For a better analysis of the developed correlations we look at those relations that have higher values of correlation coefficients (R) and smaller values of the standard error of estimation (SE). The forms of the empirical models with a good multiple correlation coefficients are given briefly below while the remainders have a lower value of R and can be neglected.

$$\frac{G_d}{G_0} = 0366 + 0.363\frac{S}{S_0}$$ *(with R=0.600 and SE=0.049)* (9)

$$\frac{G_d}{G_0} = 0.304 + 0.063S$$ *(with R=0.878 and SE=0.029)* (10)

$$\frac{G_d}{G_0} = 0.320 - 0.057\frac{S}{S_0} + 0.039S$$ *(with R=0.880 and SE=0.029)* (11)

$$\frac{G_d}{G_0} = 0.373 + 0.166\frac{S}{S_0} + 0.022S - 0.002R_H$$ *(with R=0.904 and SE=0.026)* (12)

$$\frac{G_d}{G_0} = 0.406 + 0.010\frac{S}{S_0} + 0.028S - 0.002R_H - 0.001T_a$$ *(with R=0.907 and SE=0.026)* (13)

$$\frac{G_d}{G_0} = 0.392 + 0.117\frac{S}{S_0} + 0.0263S - 0.002R_H - 0.001T_a + 0.007W_S$$ *(with R=0.912 and SE=0.025* (14)

$$\frac{G_d}{G_0} = 0.428 + 0.117\frac{S}{S_0} + 0.0262S - 0.003R_H - 0.003T_a + 0.003W_S + 2.192P$$ *(with R=0.913 and SE=0.025)* (15)

From these equations, one can notice that Eq.15 has the highest value of R (0.913) and the smallest value of SE. Estimating G_d/G_o values for Qena location used in the analysis tests the applicability of the proposed correlations in predicting G_d/G_o. However a comparison between the measured and the estimated values of G_d are done. The values of daily global solar radiation were estimated by the empirical models (Eqs. 9-15) and compared with the corresponding measured values of a new data at Qena during 2003 (182 days) and 2004 (82 days).

The results are illustrated in Fig. 7. This figure shows a small deviation between the measured and the calculated values during this period. However a linear regression between the measured and the calculated data was performed for each model. The correlation coefficients (r) between the measured and estimated data were more than 0.98 for each model. Moreover the values of daily global solar radiation were estimated by use some other models such as Trabea et al. (2000) [7] and Page (1961) [14] see Fig.7. The correlation coefficients (r) between the measured and estimated data were 0.87 and 0.98 respectively.

IV. Conclusions

The variation of daily global solar radiation and different meteorological parameters such as sunshine duration, relative humidity, air temperature, water vapor pressure, and mean sea level pressure are presented and analyzed for Qena Upper Egypt. The multiple correlation and regression coefficients have been estimated in this study to develop several correlation equations used to describe the dependence of daily global solar radiation on other meteorological data for Qena location000. Even though up to six variable correlations has been developed, it is observed that the six variable correlations which is one of the equations with the highest value of R. From the above results and considerations, the values of R and SE vary between 0.913 (Eq.15) and 0.600 (Eq.9) and 0.025 (Eq.15) and 0.049 (Eq.9) respectively. Moreover a good agreement between our models values, Page (1961) [14] model and new measurements which were not used in its deduction, confirms its performs in our region. This means these empirical models are suitable to be used in calculating the daily global solar radiation when the metrological data such as; T_a, R_H, S/S_0, S, V, P, Ws are available.

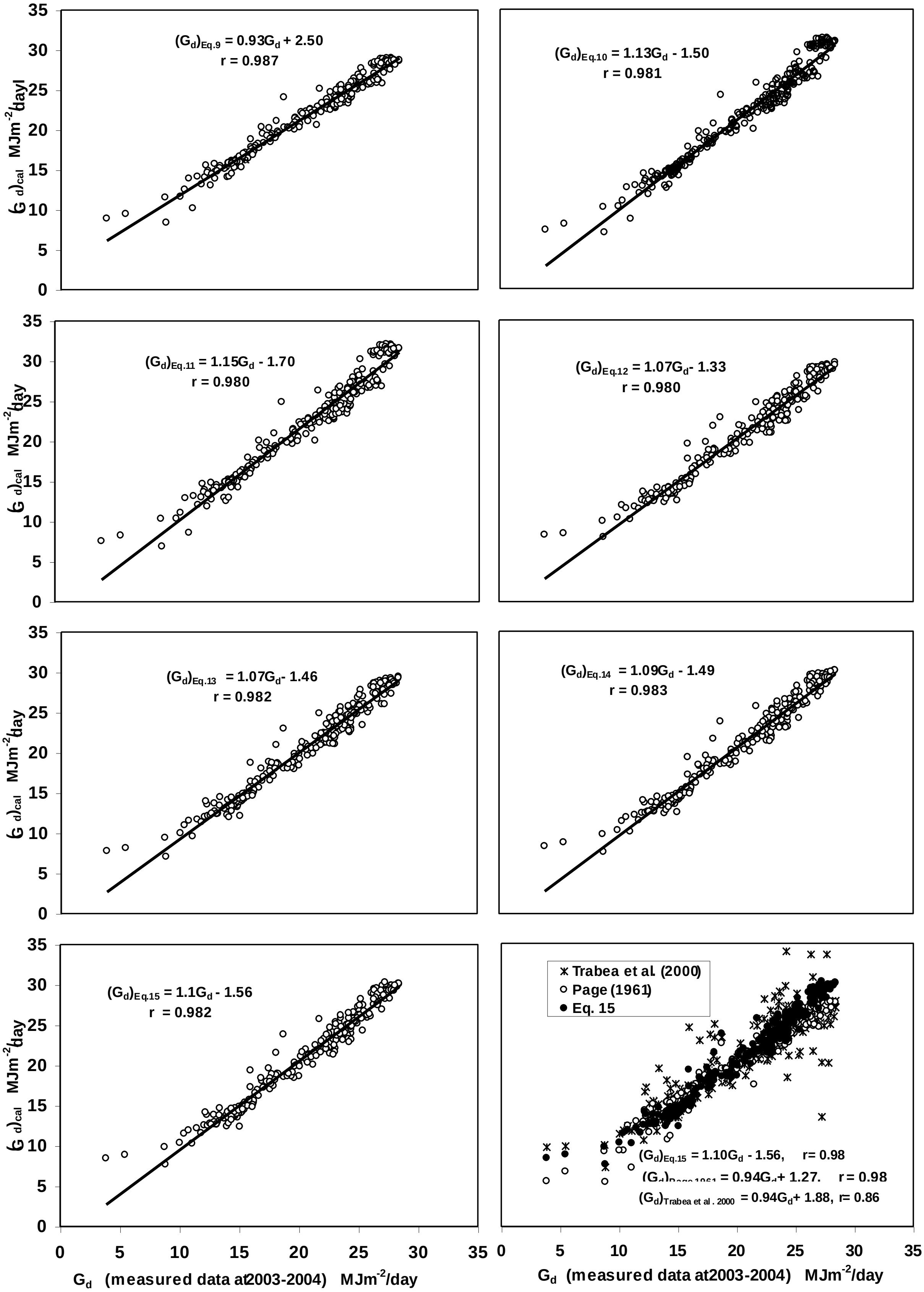

Fig 7. *Comparison between measured (Gd) and estimated (Gd)cal values of daily global solar radiation.*

REFERENCES

[1] EL-Shazly, S. M., 1994: Solar radiation components at Qena, Egypt. IDOJARAS, Quart J. Hungarian Meteorol. Service 101, 215-231.

[2] EL-Shazly, S. M., 1996: Estimation of hourly and daily global solar radiation at clear days using an approach based on Modified version of Gaussian distribution. Advances in atmospheric Sciences 13, 349-358.

[3] EL-Shazly S. M., Abdelmageed A. M., El-Nouby Adam M., 1996: Solar radiation characteristics at Qena/Egypt. IDOJARAS, Quart J. Hungarian Meteorol. Service 101, 215-231.

[4] Festa R. and Ratto C. F., 1993: Proposal of a numerical procedure to select reference years. Solar Energy 50(1), 9–17.

[5] Raja, I.A., and Twidell, J.W., 1990: Diurnal variation of global insolation over five locations in Pakistan. Solar Energy 44, 73-76.

[6] Akpabio, L.E., Sunday O., Udo, S.O. and Etuk, S.E., 2004: Empirical correlations of global solar radiation with meteorological data for Onne, Nigeria. Turk J. Phys. 28, 205-212.

[7] Trabea, A.A., and Shaltout M.A.M., 2000: Correlation of global solar radiation with meteorological parameters over Egypt. Renewable Energy 21, 297-308.

[8] Gopinathan K.K., 1988: A new model for estimating total solar in Doha. Energy onfers Mgmt 28, 63.

[9] Abdalla, Y.A.G., 1994: New correlation of global solar radiation with meteorological parameters for Bahrain. Int. J. Solar Energy 16, 111-120.

[10] Kuye, A., and Jagtap, S.S., 1992: Analysis of solar radiation data for Port Harcourt, Nigeria. Solar Energy 49, 139-145.

[11] Hulstrum, R. L., and Imamura, M., 1976: Definition study for photovoltaic residential prototype system. Final report appendix. Martin Marietta MCR 76-394.

[12] Morriss, N., James, G. E. and William, D. B., 1982: Understanding our Atmospheric Environment. W.H. Freeman Company, San Francisco.

[13] Mohamed, A., Abdelkel Kerim, F.M., Bassily, A.B., Armia, E. Nassary, M., 1987: Heavy metals determination in the atmosphere of Qena using spectroscopic Technique. Bull. Fac. Sci. Qena, Egypt.

[14] Page, J.K., 1961: The estimation of monthly mean values of daily total short-wave radiation on vertical and inclined surfaces from sunshine recorder for latitudes 40^0N –40^0S. Proc. U.N. conference on Sources of energy. Paper no. 35/S/98/3, 78-390.