Evaluation of the correlation between Ultraviolet and Broadband Solar Radiation at a subtropical location (Qena, Upper Egypt)

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Abstract - ***Although the study of ultraviolet solar radiation (UV) is important component of the environment, the concerned studies of this component are limited at Qena, Egypt (26.20, 32.70, 96 m asl). Thus, the hourly ratio of UV/G was estimated. The monthly average variation of these hourly values was discussed with respect to the change of some atmospheric parameters (ozone, water vapor and cloud). Through the whole period of this study, the average value of this ratio was compared with the same ratios of the other sites (inside and outside Egypt). In addition, a simple significant correlation between hourly values of UV and G has been established. Datasets for a new time period from Qena were used to validate the proposed equation. The study showed that, the estimated values of UV from this equation were in a good agreement with the corresponding measured values of UV (correlation coefficients was 0.94). These results were satisfactory to use these recommended correlation equation to estimate UV values that are difficult to measure or where measurements are available only for limited periods at any site in the zone of Upper Egypt. Furthermore, the study discusses the statistical results (correlation coefficients, modeling indexes, coefficients of modeling efficiency, root mean square errors, mean base errors and mean absolute errors) for the recommended correlation equation.***

Key Words: *Ultraviolet solar radiation, Global solar radiation, Atmospheric parameters, Empirical model*

1. INTRODUCTION

The solar spectrum is a mixture of radiation: visible, ultraviolet and infrared radiation. The extra-terrestrial solar spectrum has a UV component that accounts for 9.3% of total solar radiation [1]. The complete UV waveband covers the wavelength range 100-400 nm [2]. Regarding its biological effects, UV radiation can be divided into three bands: UVA "315-400 nm", UVB "280-315 nm" and UV-C "100-280 nm". The effects of UV radiation on humans, the ecosystem, animals, plants, and materials are extensively studied and reported by several authors (e.g., [3-8]).

The strength of solar beam undergoes complicated attenuation as it passes through the earth's atmosphere, where it is partially absorbed and partially scattered. The transmitted solar radiation reaches the earth's surface is then dependent on the following factors:

(i) Scattering by air molecules (Rayleigh scattering) and aerosols, which is continuous function of wavelength without selective bands.

(ii) Selective absorption by atmospheric gases (such as O3, H2O, CO_2 and O_2) at certain wavelengths. The aerosols also absorb radiation somewhat continuously in wavelengths, but much smaller than scattering by it [9]. Ozone absorbs mainly in the ultraviolet zone at wavelength less than 290 nm [10]. Water vapor absorption bands lay at the wavelength more than 700 nm. With the exception of ozone and water vapor, the main gaseous absorbers are Co_2 and O_2.

Cloudiness plays an important role in atmospheric radiation transfer [11, 12]. In additions to cloud cover, the type and height of clouds can strongly affect the transmission of solar radiation through the lower atmosphere. Day-to-day changes of UV over the northern midlatitudes are dominated by the cloud variability [13]. The effect of clouds on UV levels can vary from small enhancements to almost total reduction. Under conditions with partial cloud cover, UV radiation also depends on the cloud positions relative to the Sun and the instrument.

Consequently, the UV reaching the earth's surface has been modified by the atmosphere through which the radiation must pass. This modification is a function of the radiation path length through the atmosphere and the amount of each attenuator along that path length. The path length is determined by solar zenith angle, which is itself a function of latitude and time (of day and year).

The current study was quantified the relationship between UV and G to estimate hourly total UV in all sky conditions. This is due to the fundamental role played by ultraviolet and due to the lack of long-term measurements of its magnitude. To satisfy this aim, Escobedo et al. (2011) [14] mentioned that one practical way to estimate UV is using empirical expressions derived from the correlation between G and its spectral component. The major advantage of this empirical expression is that it is simple to use and depend only on G at the surface, i.e., the most widely available data for solar radiation worldwide. However, previous studies were developed empirical relationships between the daily or hourly integrated totals for UV as a function of those totals for G such as [15-21]. This study has taken an approach similar to those studies and has utilized hourly values of both UV and G.

Therefore, the main objective of this study is to describe the fluctuations in the ratio UV/G at Qena to examine the collected data. In addition, the monthly correlation between UV and G in the all-weather was employed. The significance and performance of the relationship between the both parameters will then be evaluated with the aid of several statistical analyses.

2. METHODOLOGY

The site of this study is located at South Valley University (SVU) at Qena (26.2°N, 32.75°E, 96 m above mean see level). Qena lies within the subtropical region and its terrain is semi-desert. The climate of Qena is characterized by a hot season from March to September and a cold season from October to February [22]. SVU-meteorological research station carried out hourly values measurements of ultraviolet solar radiation (UV, MJ $m^{-2}h^{-1}$) and global solar radiation (G, MJ m^{-2} h^{-1}) at the horizontal surface. The Egyptian Meteorological Authority (EMA) is responsible for the scientific advice and calibration of the Egyptian Monitoring Network. Also hourly values of relative humidity (RH, %) and cloud amount were provided from the same research station. In addition, total ozone column data (TOC, DU) was obtained from Total Ozone Mapping Spectrometer (TOMS) satellite (http:jwocky.gsfc.nasa.gov/ index.html) which was given around 12:00 GMT. Additional details of the TOMS satellite data are accessible in previous studies such as those of [23 – 25].

For the purpose of evaluation of the relationship between G and UV, 3411 of hourly measurements of both parameters (through the year 2001) were used. Verification results of the derived empirical models were performed through data obtained during the period from January to Joune 2002 (1592 hours). There are many sources that offer good descriptions of UV and G at SVU meteorological research station (e.g., [24]; [26; 27]. Adam (2011) [28]reported, the SVU meteorological research station carried out hourly value measurements of G (MJ $m^{-2}h^{-1}$) at the horizontal surface. The Precision Spectral Pyranometer (PSP) No. 16317IS, which is an ISO 9060 secondary standard Pyranometer with a spectral range of 295-2800 nm, was used to precisely measure global solar radiation. The PSP is the Pyranometer most commonly used by national meteorological authorities in worldwide meteorological networks. In addition, Ultraviolet irradiation is measured using an Eppley radiometer TUVR No. 31737. Its sensitivity and cosine response are approx. 150 μV/(W/m^2) and ± 3.5% from normalization 0-70^o zenith angle [25]. The Combilog Datalogger (No. 1020, TH. Friedrichs & CO. "Germany") recorded the values of hourly UV and G. The accuracy of the Pyranometer corresponds to the first class, according to the World Meteorological Organization classification.

3. RESULTS AND DISCUSSIONS

3.1 Description of the hourly values of UV/G ratio.

The purpose of this study is not to discuss the variability of UV and G but to quantify the relationship between the two parameters. Thus, this section includes only a description of the hourly variation of UV/G to examine the used data (Fig.1). According to the aim of this study, the relationship between the hourly values of both UV and G was quantified for each month and through the year 2001 (section 3.2). Finally, verification of the empirical equation through the year 2001 was done by using a new set of data from January to June, 2002 (section 3.3).

First, a clear picture of the fluctuation of hourly UV and G is obtained by investigating the values of UV/G and their frequency distribution in the study region during the period under study. Figure 1 shows the variation in hourly values of UV/G (%) at Qena through the period of this study (2001). This figure reflects the changes in this ratio from hour to hour. Over the whole period, 89.1% of these data have UV/G values from 3% to 4%. The hourly average value of this ratio was equal to 3.3%. In addition, 1.8% of the data have UV/G values more than 4%. The maximum value was equal to 7.4 and was observed on 7 January at 17:00 local standard time. Moreover, 9.1% of the data have UV/G values less than 3% (the minimum value of UV/G was 2.1% and occurred on 5 August, at 17:00 local standard time. Barbero et al. (2006) [29]and Jacovides et al. (2009) [30] mentioned that part of this variability could be explained by the strong spectral dependence of the atmospheric transmittance of the solar spectrum on the traversed optical air mass, which causes differential behavior of incoming solar UV and G. As mentioned above, discussion of the variability of UV and G, accordingly UV/G ratio, is beyond the scope of this study, but it describes the relationship between both parameters. For G and UVB/G ratio, in previous work by the authors [24; 28; 31-33], this variability was discussed at Qena.

However, for UV solar radiation, this effect will be studied in details in the forthcoming paper. Here, the variation of the monthly averages of hourly UV/G was shown in Figure 2, as well as the fluctuation of monthly average of hourly atmospheric parameters (available results such as TOC, RH and CA).

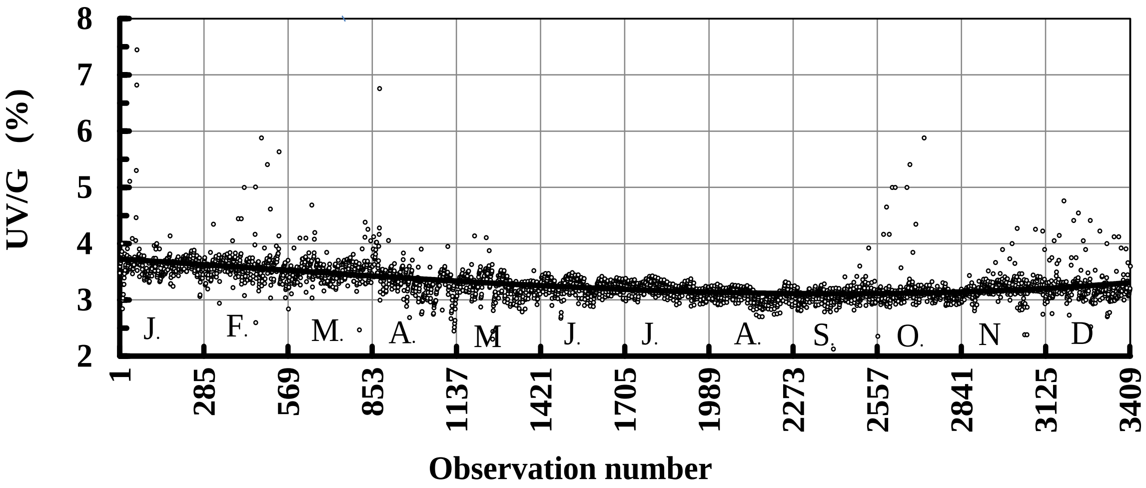
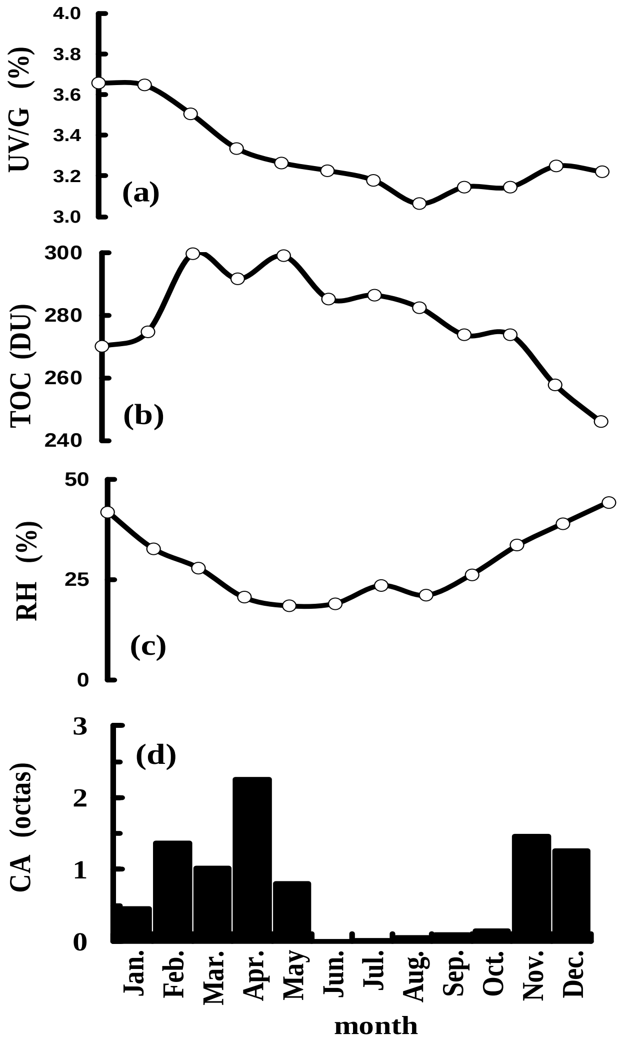


Fig- 1: Hourly ratio UV/G (%) under all sky conditions at Qena for 2001.

__Fig-2:__ Monthly average of hourly ratio UV/G, % (a), total ozone column, TOC in DU (b), relative humidity, RH % (c) and cloud amount, CA octas (d) at Qena for 2001.



From Fig.3, there was no a clear variation of the monthly average of hourly UV/G ratio with respect to each separated atmospheric parameter (such as TOC, RH and CA, Fig.2 (b, c and d), respectively). Although the correlation coefficient between the monthly average of both UV/G and each atmospheric parameter (TOC, RH and CA) was very week (0.12, 0.34 and 0.17, respectively), the multiple correlation was good (0.80) with standard error of estimate (SEE) equal to 0.34%.. This means that, approximately, 64% of the change of UV/G is due to the variations of these atmospheric parameters. The effect of water vapor was relatively grater the effect of TOC and CA. This is due to the absorption bands of solar radiation by water vapor in the atmosphere lie in higher wavelength bands >700 nm [18]. However, the absorption bands of solar radiation by ozone in the atmosphere lie in lower wavelength (UV bands). This means, water vapor decreases G and it has no effect on UV. Thus, this parameter has a clear effect in the UV/G.

3.2 Correlation between hourly UV and G

According to the aim of this study, here the relationship between the hourly values of both UV and G at Qena was quantified. Figure 3 illustrates the relationship between the hourly values of both parameters. From Fig.3, the values of UV increase with increase of G. This enabled us to investigate an empirical relationship between them. Many types of correlation (Linear, Second and Third order polynomial, and Power) were tried to find out the best fit between G and UV data through the period of this study. According to our results, the all types of correlation showed coefficient of determination (R^2) between the two variables more than 0.98. For simplicity, a linear relation between the two components was considered. Earlier studies supported the results of the present work; however, they reported that the correlation between UV and G was described by a linear equation [15; 17; 18; 19; 20; 21; 35]. The following functional relation between the two components was obtained:

$$UV = S_1 G\,, \tag{1}$$

The coefficient of determination (R^2) of this relationship was 0.98 at a confidence level of 99% (i.e. 98% of the variability has been explained by the computed regression line). The value of the empirical coefficient S1 (which represents the ratio UV/G) was found to be equal to 3.3%. This means that, on average, the UV radiation constitutes approximately 3.3% of the global solar radiation (with SEE =0.54%). Table 1 refers to the variation of the empirical coefficient S1, correlation coefficient (R) and SEE for each month. In addition, graphically, Fig.4 includes the relationship between the hourly values of both UV and G for each month.

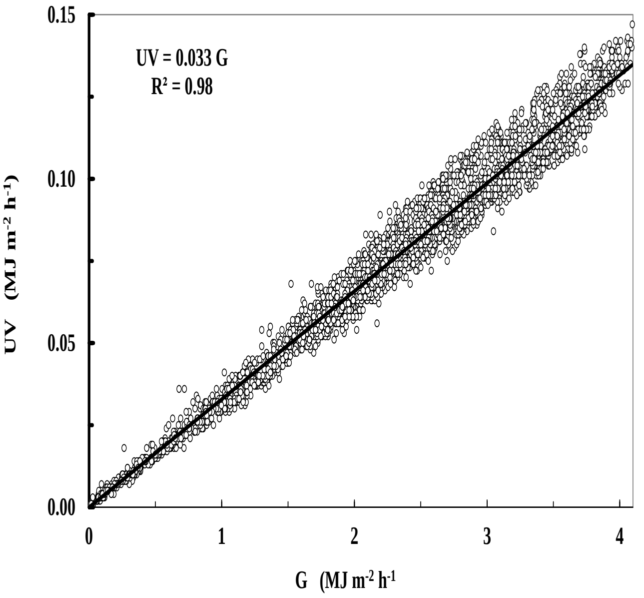


Fig-3: *hourly ultraviolet solar radiation, UV (MJ m^{-2} h^{-1}) vs. hourly global solar radiation, G (MJ m^{-2} h^{-1}) at Qena for 2001 (◦ hourly values, – linear regression).*

From Table 1, it can be seen that the monthly averages of the hourly values of UV/G (S1) varied from 3.1% in August to 3.7% in January. The correlation coefficients between both components were greater than 0.99 (with SEE less than 0.53%). This monthly average variation of the hourly values of UV/G may be due to the change of the atmospheric factors that have a different effect in the solar radiation components. According to the earlier studies, the atmospheric compounds that show the strongest influence on UV radiation are the ozone, the aerosols and the clouds. In addition, other gases control the radiation levels in the G range at the ground, for example the water vapor [30; 36-38]. As mentioned above, this effect will be studied in details in the forthcoming paper. It is known that, the effect of these parameters in the solar radiation depends on the wavelengths.

Table -1: *Monthly average of hourly values of UV/G (S_1, %), correlation coefficient (R) and standard error of estimation (SEE).*

Month	S_1 (%)	R	SEE
Jan.	3.7	0994	0.0031
Feb.	3.6	0.996	0.0029
Mar.	3.5	0.997	0.0033
Apr.	3.4	0.991	0.0053
May	3.3	0.996	0.0031
Jun.	3.2	0.996	0.0030
Jul.	3.3	0.997	0.0028
Aug.	3.1	0.997	0.0045
Sep.	3.1	0.997	0.0027
Oct.	3.1	0.997	0.0028
Nov.	3.2	0.997	0.0028
Dec.	3.2	0.996	0.0023

Table 2 compares the average value of UV/G through the period of this study with the corresponding values for other locations. The table reflects that, this ratio at Qena was in comparable with those values over some other Egyptian cities such as Cairo "3.5%" [15]. Furthermore, UV/G was nearest to its value for Almería "3.7%" [17]. However, it is smaller than those values for Kwangju "7.2%" [18], Cordoba "4.2%" [19], Granada "4.0%" [17], Kuwait "4.6%" [20] and Botucatu "4.2%" [21]. It is greater than the value for Valencia "2.9%" [39]. Accordingly, the ratio of both components changes for each place. This difference is due to the dependence of these values on the atmospheric conditions of each location. Therefore, it can be concluded that this simple relationship between both components is not of application to localities with different climatic conditions [17].

3.3 Verification of empirical equation

The measured data of G during a new period (from January to June, 2002) were introduced in Eq. 1 to estimate the corresponding values of UV. These estimated values were compared with the corresponding measured values during the mentioned period. The results were illustrated in Fig. 5. From this figure, it can be seen that the estimated values of hourly UV (UVe) are in a good agreement with the corresponding measured values (UVm). The correlation coefficient (R) was 0.94 (with SEE =1%). This means that, approximately, the computed regression line has explained 90% of the variability.

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Although the value of R between the measured and estimated values of UV was good, this does not automatically indicate good model accuracy [42]. Therefore, additional statistical parameters were used to assess model performance such as: an index of modeling or modeling index, d; coefficient of modeling efficiency, ME; root mean square error, RMSE; mean base error, MBE and mean absolute error, MAE [40- 42]. One can calculate these statistical parameters as following:

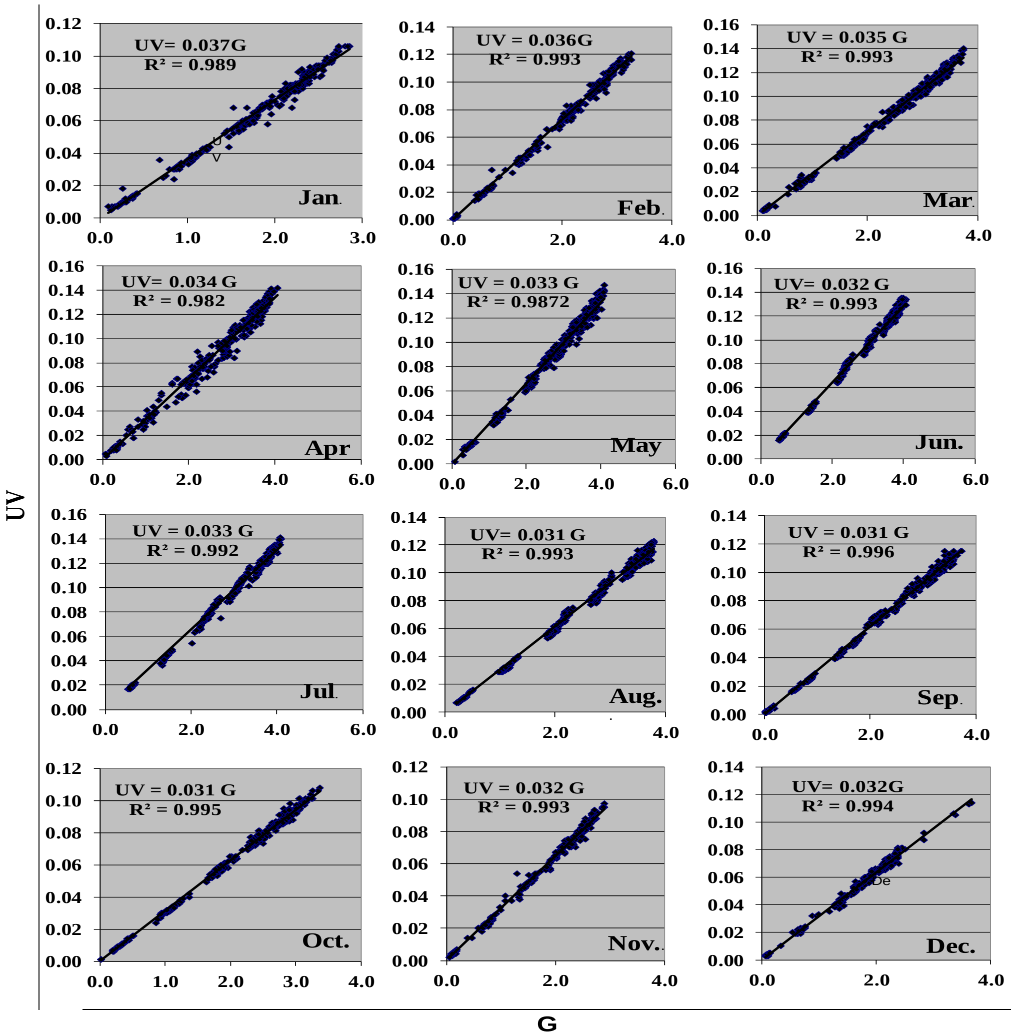

Fig-4: *Hourly ultraviolet solar radiation, UV (MJ m^{-2} h^{-1}) vs. hourly global solar radiation, G (MJ m^{-2} h^{-1}) at Qena for each month (● hourly values, – linear regression).*

Table-2: *Comparison of UV/G ratio (%) of the present study with other studies.*

Study area (Lat., Long.)	UV/G %	Land use	Authors
Valencia (39.5° N,0.341° W)	2.9	Urban (near to the ocean)	Martinez-lozano et al., 1994
Qena (26.17° N, 32.72° E)	3.3	Urban	El-Nobi, 2006
Qena (26.17° N, 32.72° E)	**3.3**	Urban	**The present study**
Cairo (30. 08° N, 31.28° E)	3.5	Urban	Robaa, 2004
Almería (36.83° N, 2.41°W)	3.7	Urban (seashore location)	Foyo-Moreno, et al., 1999
Granada (37.18° N, 3.58°W)	4.0	Urban	Foyo-Moreno, et al., 1999
Córdoba (37.89° N,4.76° W)	4.2	Urban	Cañada et al., 2003
Botucatu (22.88° S,48.43° W)	4.2	Rural	Escobedo et al. 2009

Kuwait (29.38° N, 47.99°E)	4.6	Urban	Al-Aruri, 1990
Kwangju (35..89°N,126.93°E)	7.2	Urban	Ogunjobi and Kim, 2004

$$d = 1 - \left[\frac{\sum_{i=1}^{n} (x_i - y_i)^2}{\sum_{i=1}^{n} \left(\left| x_i - \bar{x}_i \right| + \left| y_i - \bar{x}_i \right| \right)^2} \right],$$

$$ME = 1 - \left[\frac{\sum_{i=1}^{n} (x_i - y_i)^2}{\sum_{i=1}^{n} \left(\left| x_i - \bar{x}_i \right| \right)^2} \right],$$

$$RMSE = \sqrt{\frac{1}{n} \sum \left[\sum_{i=1}^{n} (x_i - y_i)^2 \right]},$$

$$MBE = \frac{1}{n} \left[\sum_{i=1}^{n} (x_i - y_i) \right],$$

$$MAE = \frac{1}{n} \left[\sum \left| x_i - y_i \right| \right],$$

where x_i are the measured values with a mean of (x bar), and y_i are the estimated values. The values of d will vary between zero and one, with a value of one indicating perfect model agreement. In addition, ME will vary between minus infinity and one with higher values (closer to 1) indicative of superior model performance [43]. These statistical results summarize that, the model performed well over the study area. The value of d and ME were 0.92 and 0.74 respectively. This indicates the estimated values were good agreement with the measured values of UV. In addition, the values of RMSE, MBE and MAE were 0.0125, 0.0071 and 0.0072, respectively.

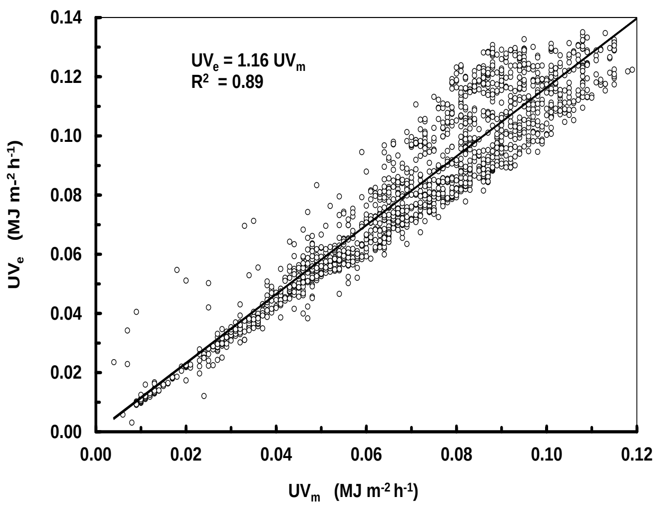

Fig-5: *Scatter plot of estimated versus measured values of ultraviolet global solar radiation, UV_e and UV_m, respectively (◦ hourly values, – linear regression).*

From the above discussions, the relationship between UV and G gives an impressive result that can be applied to estimate UV values that are difficult to measure or where measurements are available only for limited periods at Qena or any site in the zone of Upper Egypt that has the similar climate. As mentioned in the previous works [17; 18], the use of nondimensional parameters can be used to reduce local characteristics of those correlations.

4. CONCLUSIONS

The present study is an attempt to describe the relationship between ultraviolet and global solar radiation and the impact of the atmospheric parameters on both components at the earth's surface. The results could be summarized in the following:

- The hourly values of ultraviolet and global solar radiation over a horizontal surface have been analyzed for Qena - Egypt (26.20, 32.70, 96 m asl). On average, the hourly UV radiation constitutes approximately 3.3% of the hourly global solar radiation.
- A simple relationship between UV and G components was established in the form of equation (1) R was 0.99 with SEE equal to 0.54%. This simple relation can be used to estimate the hourly ultraviolet from the global solar radiation at Qena or any site in the zone of Upper Egypt that has the similar climate.
- this study showed a seasonal variation of the UV/G ratio. However, the monthly mean variation of hourly UV/G varied from 3.11% at August to 3.71% at January. Approximately, 80% of this monthly change of UV/G is due to the variations of the atmospheric parameters such as TOC, RH and CA.

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