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Calculation of the Global Solar Radiation in a Subtropical Region (Qena, Egypt)

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A B S T R A C T

Air temperature (T, °C), relative humidity (RH, %), and global solar radiation (G, $MJ.m^{-2}$) have been measured in the meteorological station at South Valley University (SVU) at Qena, Egypt, from 2000 to 2013, while the total column ozone (TCO, DU) is downloaded from Giovanni's website. T, RH, and TCO are important meteorological parameters, and they are useful to estimate the missing data of the global solar radiation (G), as global solar radiation is desirable for electricity generation applications and for agriculture. Qena is a subtropical region in Upper Egypt, as it's characterized by clear weather most days of the year, and it's very hot in the summer and cold in the winter. The meteorological station at South Valley University (SVU) stopped measuring the G. The linear regression equation and the most important statistical indices are used in this paper such as, the determination coefficient (R^2), the mean absolute error (MAE), the mean absolute bias error (MABE), the mean square error (MSE), the root mean square error (RMSE), the mean percentage error (MPE), the mean bias error (MBE), the model efficiency (ME), and the agreement index (d). For verification of the empirical models' efficiency, the data of a new period has used, 2013, and the results of the models were excellent and valid for estimating the missing data, as R^2 was more than 0.92 in all models but it was near one in models 1 and 4. MAE was close to zero for all models. MBE, MPE, and MABE were close to zero for all models except model 3. Model 1 was the best one, as, R^2, MAE, MABE, MSE, RMSE, MAPE, d, ME, and MPE were 0.9883, 0.0193, 0.383, 0.2303, 0.4799, 1.927, 0.9979, 0.992, and 0.2932, respectively.

Keywords: Global solar radiation, air temperature, relative humidity, Subtropical region, Qena, Egypt.

Introduction

Solar radiation is the main driver of all the forces and phenomena that occur in the atmosphere and is also important for all biological processes that occur on the surface of the earth, and the demand for energy has increased in recent years and the sun is an important source of permanent energy, and Egypt has already built solar stations to generate electricity [1], [2]. Meteorological parameters are strongly affected by solar radiation, so they are useful in predicting missing values from the data series. There were many previous local attempts to measure the intensity of solar radiation, but over short periods of time [3]–[5], but what is new in this research is that these measurements have not been recorded before, and models such as this work have not been analyzed before in the study area. The main problem is the inability of the meteorological station to provide us with data on solar radiation in the future because of the high cost of operating and maintaining the measuring device, and this is a bad thing because solar radiation is very important for plants that are food for humans and animals, as it helps them in the process of photosynthesis [6]. Meteorological parameters such as air temperature, relative humidity, sunshine duration, wind speed, and total column ozone can be used to expect solar radiation values and are an easy and simple way in particular in the case of regression equations simple and here has been building more than a model Where the parameters that can be obtained easily were used [7]–[10].

Methodology

The hourly global solar radiation (G_h) on the horizontal surface, the relative humidity (RH), and the air temperature (T)were measured by the meteorological station at South Valley University, at Qena (26° 17' N, 32° 10' E, and 96 m above sea level), Egypt. It's 600 kilometers (km) south of Cairo and 260 km west of the Red Sea [11]. It's a subtropical region, also it has a clear sky most days of the year, hot summer, and cold winter. G_h was measured using a Precision Spectrophotometer (PSP) No. 16317IS, as its spectral range is from 295 nm to 2800 nm. The Egyptian Meteorological Authority (EMA) is responsible for the calibration of the devices at the station. The daily total column ozone (TCO) has been downloaded from the Giovanni website (https://giovanii.gsfc.nasa.gov/giovanni/). For the data quality, the not logical data has been rejected. The measured daily values of global solar radiation (G) must verify the condition $G \leq 1.2\ G_o$, as G_o is extraterrestrial solar radiation [12]. The used equations to calculate the daily G_o in $MJ.m^{-2}$, and the maximum possible sunshine duration S_o in hours [13] are:

- $G_o = \frac{24 \times 3.6 \times 10^{-3} \times I_{sc}}{\pi} \left[1 + \text{Cos}\left(360 \frac{d_n}{365}\right)\right] [\text{Cos } \Phi \text{ Cos } \delta \text{ Sin } \omega_S + \omega_S \text{ Sin } \Phi \text{ Sin } \delta]$
- $UV - B_o = \frac{24 \times 3.6 \times 10^{-3} \times I_{UV-B}}{\pi} \left[1 + \text{Cos}\left(360 \frac{d_n}{365}\right)\right] [\text{Cos } \Phi \text{ Cos } \delta \text{ Sin } \omega_S + \omega_S \text{ Sin } \Phi \text{ Sin } \delta]$
- $S_o = \frac{2}{15} \omega_S$
- $\delta = 23.45 \text{ Sin}\left(360 \frac{248 + d_n}{365}\right)$, and $\omega_S = \text{Cos}^{-1} [- \tan \Phi \tan \delta]$.

As I_{sc} = 1367 Wm^{-2} is the solar constant, d_n is the number of the special day of each month: d_n = 1 on January 1st and increases to 365 on December 31st or to 366 in the leap year, Φ is the latitude of the location (26.2°), δ is the solar declination angle, and ω_S is the sunset hour angle. In addition, the used equations to calculate the determination coefficient (R^2)[14], the model efficiency coefficient (ME), the model agreement factor (d), the mean absolute error (MAE), the mean absolute bias error (MABE), mean absolute percentage error (MAPE), the mean percentage error (MPE), the root mean square error (RMSE) and mean bias error (MBE)[15]–[19] are:

- $R^2 = 1 - \left[\frac{[\sum(m - c)]^2}{\sum(m - \overline{m})^2}\right]$
- $ME = 1 - \left[\frac{\sum(m - c)^2}{\sum(|m - \overline{m}|)^2}\right]$
- $d = 1 - \left[\frac{\sum(m - c)^2}{\sum(|m - \overline{m}| + |c - \overline{m}|)^2}\right]$
- $MAE = \frac{1}{n} \sum \left|\frac{(m - c)}{c}\right|$
- $MABE = \frac{1}{n} \sum | m - c |$
- $MPE (\%) = \frac{\sum[100 \frac{(m-c)}{m}]}{n}$
- $RMSE = \sqrt{\frac{\sum (m-c)^2}{n}}$
- $MBE = \frac{\sum(c-m)}{n}$

As n, m, c, $\overline{m}$, and $\overline{c}$ are the number of the values, the measured value, the estimated value, the average of the measured value, and the average of the estimated value, respectively.

Results and Discussion

Figure (1) shows the average of the daily values of G, T, RH, and TCO from April 2000 to December 2012, as we note that G, T, and TCO have the same pattern and change in the same way but RH changes in the opposite way. The data from 2000 to 2012 is used to derive the empirical equations, and they were:

1- G= Go (0.0266 T+0.01525) ±11.9

2- G= Go (0.02203 RH+0.01264) ±9.9

3- G= Go (0.00235 TCO+0.001348) ±2.43

4- G= Go (0.000312 T+0.000179 RH+0.000432 TCO) ±21.6

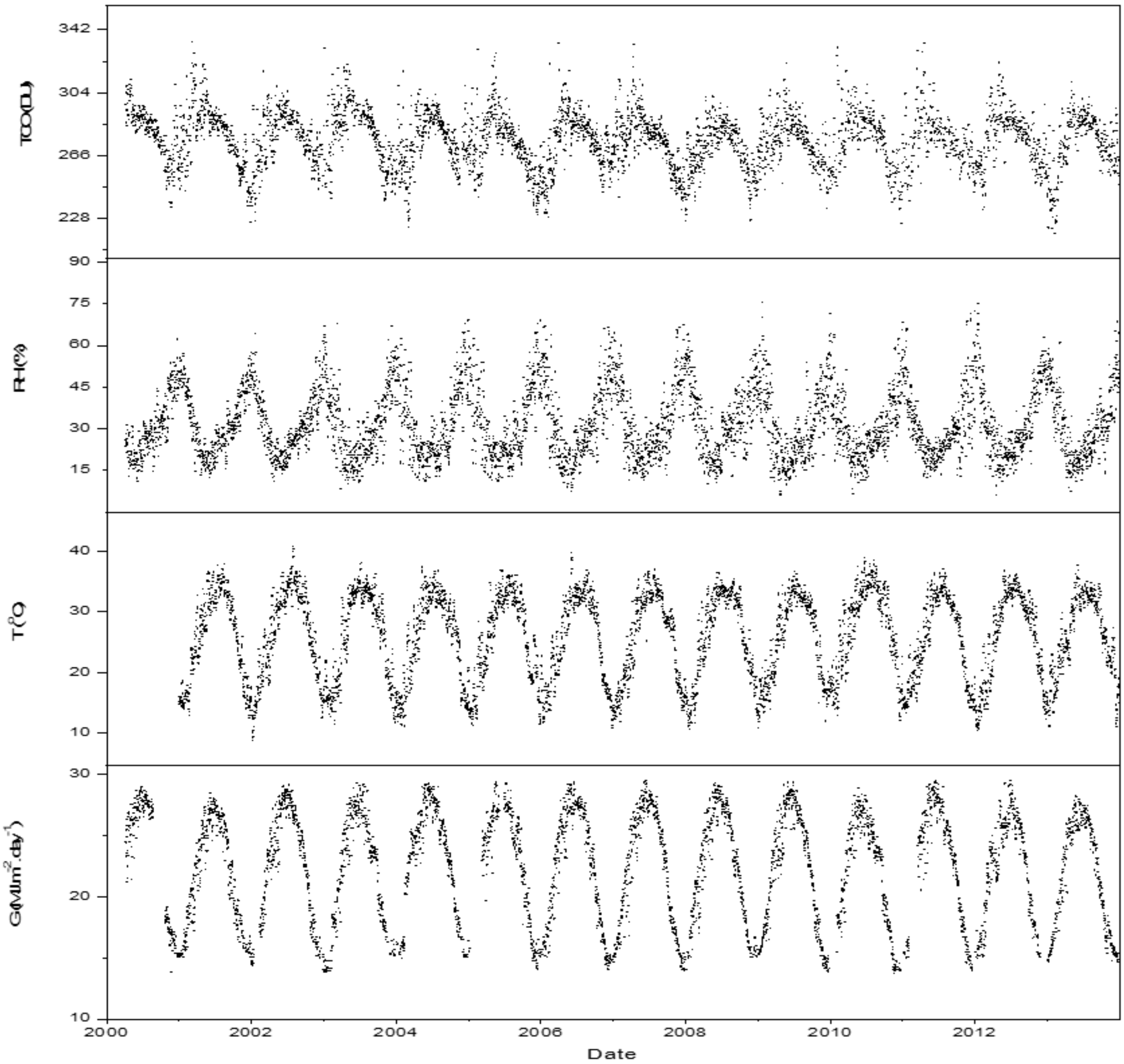

Figure (1): The time series of TCO, RH, T, and G at Qena (2000, 2013)

4. Verification of the empirical models

Figure (2) shows the comparison between measured and estimated daily global solar radiation (G) for the data of 2013 as a new period, and table (1) represents the statistical indices for the models. We can note the great agreement between the measured (G_m) and estimated (G_d) values of daily global solar radiation, as R^2 was more than 0.92 in all models but it was near one in models 1 and 4. d and ME were close to one in the model 1, otherwise, MAE was close to zero for all models. MBE, MPE, and MABE were close to zero for all models except model 3. RMSE was 0.4799 $MJ.m^{-2}.day^{-1}$ in model 1, as it was the absolute minimum value. We can notice that model 1 was the best among them.

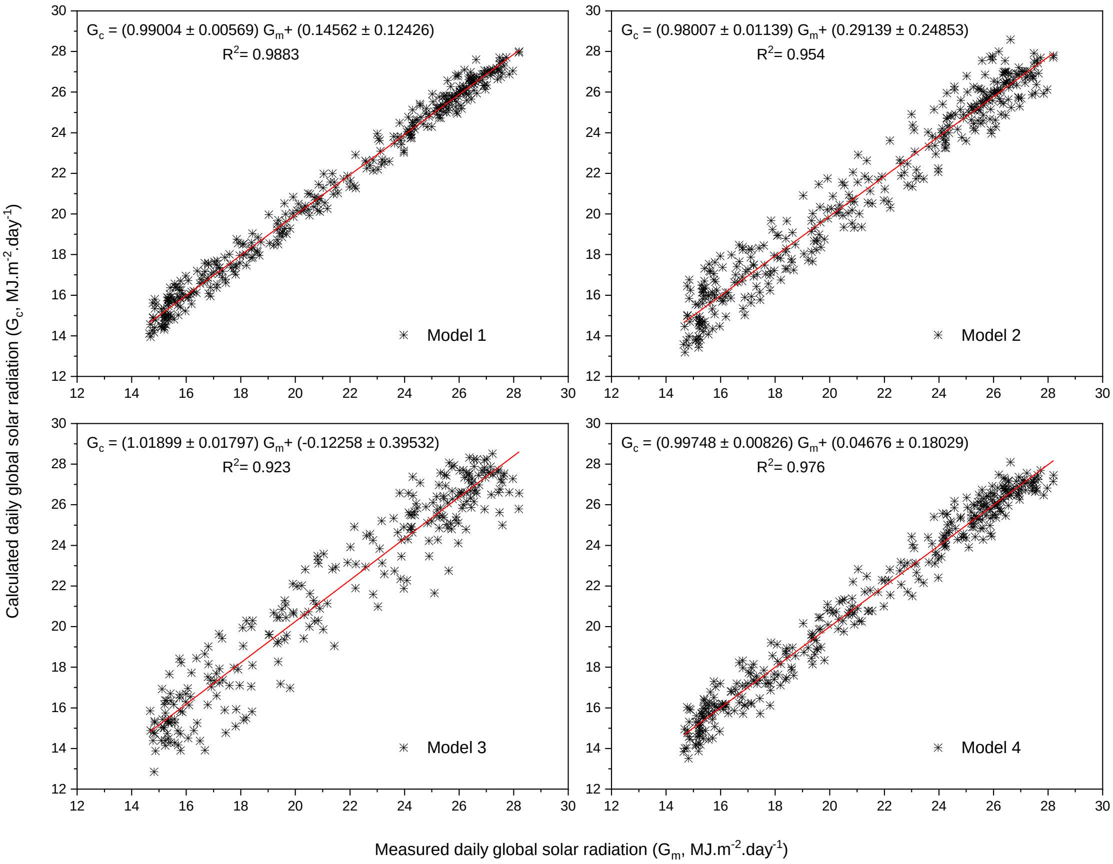

Figure (2): Comparison between Gm and Gc at Qena (2013) using the models

Table (1): Statistical tests for comparison between the models

Model	MAE	MBE	MABE	MSE	RMSE	MAPE	MPE	R2	ME	d
1	0.0193	0.0684	0.383	0.2303	0.4799	1.927	0.2932	0.9883	0.992	0.9979
2	0.0389	0.1317	0.766	0.9216	0.9599	3.856	0.5509	0.954	0.966	0.9914
3	0.0381	4.9301	5.943	113.18	10.639	28.567	23.7548	0.923	-3.186	0.5612
4	0.0272	0.0471	0.588	1.0471	1.0233	2.99	0.3075	0.976	0.961	0.9905

5. Conclusion

The aim of the work was to calculate the missing data of the daily global solar radiation (G, $MJ.m^{-2}$) by using air temperature (T, °C), relative humidity (RH, %), and total column ozone (TCO, DU), as the models had high efficiency to estimate missing data of G. The most important statistical tests are used. Model 1 was the best one, as, R^2, MAE, MABE, MSE, RMSE, MAPE, d, ME, and MPE were 0.9883, 0.0193, 0.383, 0.2303, 0.4799, 1.927, 0.9979, 0.992, and 0.2932, respectively.

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