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Validation of the existing models for estimating diffuse solar radiation over Egypt

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Abstract— The main objective of this study is to review and test the applicability of well-established models collected from the literature for estimating the monthly average daily diffuse solar radiation on a horizontal surface in Egypt. The different meteorological data measured at eight stations during the period 1987–2016 were used to calculate the monthly mean values of diffuse solar radiation over these stations using the collected models. The selected eight stations measure diffuse solar radiation component and have been chosen to cover the whole of Egypt. The collected models (fourteen models) were compared on the basis of many statistical error tests such as the relative percentage error, (*e%*), mean percentage error (*MPE*), mean bias error (*MBD*), root mean square error (*RMSE*), *t*-test, and Nash-Sutcliffe equation (*NSE*). According to the results, the Tarhan and Sarı model (Model 12) showed the best estimation of the diffuse solar radiation on a horizontal surface for all of the eight stations, and therefore, it is recommended for predicting diffuse solar radiation at any location in Egypt.

Key-words: solar energy, diffuse solar radiation, sunshine duration, extraterrestrial radiation, solar radiation models, model comparison, Egypt.

1. Introduction

Knowledge of local solar radiation components is essential in the design and study of many solar energy applications (*Lu et al,* 1998; *Li* and *Lam,* 2000; *Wong* and *Chow,* 2001; *Driesse* and *Thevenard,* 2002; *Almorox* and *Hontoria,* 2004; *Al-Mohamad,* 2004; *Kumar* and *Umanand,* 2005). Although Egypt is a vast country and has abundant solar energy, solar radiation measurements are not easily available in Egypt (especially the diffuse solar radiation) because of not being able to afford the measuring equipments and techniques involved (*Ibrahim,* 1985). Therefore, it is important to develop methods to estimate the solar radiation on the basis of the more readily available meteorological data. Several models have been developed to estimate the amount of global solar radiation on horizontal surfaces in Egypt (*Ibrahim,* 1985; *Sabbagh,* 1977; *El-Shahawy,* 1984; *El-Shazly,* 1998; *Trabea* and *Shaltout,* 2000; *Darwish* and *Taha,* 2000; *Tadros,* 2000; *El-Metwally,* 2004 and 2005; *El-Sebaii,* and *Trabea,* 2005; *Khalil* and *Shaffie,* 2013; *El-Metwally* and *Wald,* 2013; *Khalil* and *Shaffie,* 2016). Unfortunately, the diffuse radiation measurements are very rare in Egypt, and there are no researches, except for the study of *El-Sebaii* and *Trabea* (2003), which made a concerning estimation of diffuse solar radiation in Egypt. Therefore, the main objective of this paper is to validate the best available models that predict the monthly mean daily diffuse radiation on a horizontal surface against an independent data set over Egypt, and thus, to select the most accurate model. All the most accurate empirical models which are used to estimate diffuse solar radiation, *D*, have been collected from literatures to evaluate the applicability of these models to estimate *D* over different stations in Egypt. The collected models were compared on the basis of many statistical error tests.

2. Comparison of models with literature

The most accurate empirical models concerning estimation of diffuse solar radiation collected from the literature are as follows:

Model 1 (*Hawas* and *Muneer,* 1984):

$$\frac{D}{H} = 1.35 - 1.6075\left(\frac{H}{H_0}\right), \tag{1}$$

Model 2 (*Ulgen* and *Hepbasli,* 2009):

$$\frac{D}{H_0} = 0.1155 - 0.1958\left(\frac{H}{H_0}\right), \tag{2}$$

Model 3 (*Gopinathan,* 1988):

$$\frac{D}{H} = 0.697 - 0.577\left(\frac{n}{N_o}\right), \tag{3}$$

Model 4 (*Jamil* and *Akhtar,* 2017):

$$\frac{D}{H} = 0.2932 - 1.8655\left(\frac{H}{H_0}\right) - 1.5114\left(\frac{n}{N_o}\right), \tag{4}$$

Model 5 (*Gopinathan,* 1988):

$$\frac{D}{H} = 0.879 - 0.575 \left(\frac{H}{H_0}\right) - 0.323 \left(\frac{n}{N_o}\right), \tag{5}$$

Model 6 (*El-Sebaii et al.* 2010):

$$\frac{D}{H_0} = 3.0020 - 3.8820 \left(\frac{H}{H_0}\right) - 0.1500 \left(\frac{n}{N_o}\right), \tag{6}$$

Model 7 (*El-Sebaii* and *Trabea,* 2003):

$$\frac{D}{H} = -0.209 + 2.183 \left(\frac{n}{N_o}\right) - 1.785 \left(\frac{n}{N_o}\right)^2, \tag{7}$$

Model 8 (*Tarhan* and *Sarı,* 2005):

$$\frac{D}{H} = 0.9885 - 1.4276 \left(\frac{H}{H_0}\right) + 0.5679 \left(\frac{H}{H_0}\right)^2 , \tag{8}$$

Model 9 (*Jamil* and *Akhtar,* 2017):

$$\frac{D}{H} = 0.3116 + 1.8043 \left(\frac{H}{H_0}\right) + 0.0501 \left(\frac{H}{H_0}\right)^2 - 1.5118 \left(\frac{n}{N_o}\right), \tag{9}$$

Model 10 (*Jamil* and *Akhtar,* 2017):

$$\frac{D}{H} = 0.3017 - 1.8726 \left(\frac{H}{H_0}\right) - 1.5454 \left(\frac{n}{N_o}\right) + 0.0212 \left(\frac{n}{N_o}\right)^2, \tag{10}$$

Model 11 (*Jamil* and *Akhtar,* 2017):

$$\frac{D}{H_0} = -0.1776 + 1.6206 \left(\frac{H}{H_0}\right) - 0.6843 \left(\frac{n}{N_o}\right) - 0.2136 \left(\frac{n}{N_o}\right)^2, \tag{11}$$

Model 12 (*Tarhan* and *Sarı,* 2005):

$$\frac{D}{H} = 1.0207 - 1.6582 \left(\frac{H}{H_0}\right) + 1.1018 \left(\frac{H}{H_0}\right)^2 - 0.4019 \left(\frac{H}{H_0}\right)^3 , \tag{12}$$

Model 13 (*Aras et al.* 2006):

$$\frac{D}{H} = 1.7111 - 4.9062 \left(\frac{H}{H_0}\right) + 6.6711 \left(\frac{H}{H_0}\right)^2 - 3.9235 \left(\frac{H}{H_0}\right)^3 , \tag{13}$$

Model 14 (*Jamil* and *Akhtar,* 2017):

$$\frac{D}{H} = 0.2191 + 2.3964 \left(\frac{H}{H_0}\right) - 0.3877 \left(\frac{H}{H_0}\right)^2 - 1.7828 \left(\frac{n}{N_o}\right) + 0.1705 \left(\frac{n}{N_o}\right)^2, \tag{14}$$

where D is the monthly average of the daily diffuse solar radiation, H is the monthly average of the daily global solar radiation, H_o is the monthly average daily extraterrestrial radiation, n is the day length, and N_o is the maximum possible sunshine duration. H_o was calculated from the following equation (*Duffie,* 1991):

$$H_o = \frac{24}{\pi} I_s f (\cos\varphi \cos\delta \sin w + \frac{2\pi}{360} w \sin\varphi \sin\delta) , \tag{15}$$

where I_s is the solar constant (=1367Wm^{-2}), f is the eccentricity correction factor of the Earth's orbit, φ is the latitude of the site, δ is the sun declination, and w is the mean sunrise hour angle for the given month. f, δ, w, and N_o can be computed by the following equations (*Duffie,* 1991):

$$f = \left(1 + 0.033 \cos \frac{360n'}{365}\right), \tag{16}$$

$$\delta = 23.45 \sin\left[\frac{360(284 + n')}{365}\right], \tag{17}$$

$$w = \cos^{-1}(-\tan\varphi \tan\delta) , \tag{18}$$

$$N_o = 2w/15 , \tag{19}$$

where n' is the day of the year.

3. Data and comparison methods

In this study, monthly mean values of global solar radiation and sunshine hours measured at of eight stations during the period 1987–2016 have been obtained from the Egyptian Meteorology Authority (EMA) to calculate the diffuse solar radiation, D over these stations using the above corresponding models. *Table 1* gives the list of the stations and their coordinates in addition to the type of the measured radiation at each station and its date of commencement of records. The monthly mean values of extraterrestrial solar radiation, H_o, and the day length, n, were calculated for each month of the year and for each station using Eqs. (15–19), and they were then employed to estimate D for each station.

Table 1. Coordinates of the Egyptian radiation measurements network and the radiation components measured together with the date of commencement of recording

Station	Latitude (N)	Longitude (E)	Elevation (m)	Measurement				Date of commencement of records*
				G	*D*	*I*	*S*	
Sidi-Barrani	31°38’	25°24’	27	X	X	-	X	1984
Matruh	31°20’	27°13’	38	X	X	-	X	1961 (1981)
El-Arich	31°05’	33°49’	32	X	X	-	X	1980
Tahrir	30°39’	30°42’	16	X	X	-	X	1960 (1981)
Cairo	30°05’	31°17’	36	X	X	X	X	1969 (1974)
Qena	26°03’	32°12’	96	X	X	-	X	1979
El-Kharga	25°27’	30°32’	78	X	X	-	X	1964 (1981)
Aswan	23°58’	32°47’	192	X	X	-	X	1972 (1981)

* The year in brackets indicates the data of commencement of diffuse and/or direct solar radiation records.

G is the global solar radiation; *D* is the diffuse solar radiation,
I is the direct solar radiation, and *S* is the sunshine duration.

The calculated values of diffuse solar radiation, D_c, were compared with the corresponding mean measured values, D_m (mean of the period 1987–2016) in each model. Moreover, the performance of the models was also evaluated on the basis of the following statistical error tests: relative percentage error (*e*%), mean percentage error (MPE), mean bias error (MBE) root mean square error (RMSE), t-statistic (t), and Nash–Sutcliffe equation (NSE). *e%, MPE, MBE, RMSE, t* and *NSE* are defined by Equations (20–25), respectively, as below (*Tiba,* 2001; *Ulgen* and *Hepbasli,* 2003 and 2004; *Notton et al.* 2004; *Soares et al.* 2004; *Tymvios et al.* 2005; *Mediavilla et al.* 2005; *Ulgen* and *Hepbasli,* 2002; *Togrul* and *Togrul,* 2002; *Stone,* 1993; *Chen et al.,* 2004):

$$e = [(D_{i,m} - D_{i,c}) / D_{i,m}]*100 \, , \tag{20}$$

$$MPE = \sum_{i=1}^{N} \frac{[(D_{i,m} - D_{i,c}) / D_{i,m}]*100}{N} \, , \tag{21}$$

$$MBE = \sum_{i=1}^{N} \frac{(D_{i,m} - D_{i,c})}{N} \, , \tag{22}$$

$$RMSE = \left(\frac{\sum_{i=1}^{N} (D_{i,m} - D_{i,c})}{N} \right)^{0.5}, \qquad (23)$$

$$t = \left(\frac{(n-1)MBE^2}{RMSE^2 - MBE^2} \right)^{0.5}, \qquad (24)$$

$$NSE = 1 - \frac{\sum_{i=1}^{N} (\boldsymbol{D}_{i,m} - \boldsymbol{D}_{i,c})^2}{\sum_{i=1}^{N} (\boldsymbol{D}_{i,m} - \bar{\boldsymbol{D}}_{i,c})^2}, \qquad (25)$$

where $D_{i,m}$ and $D_{i,c}$ are the ith measured and calculated values of diffuse solar radiation, respectively, while N is the number of observations taken into account.

4. Results and discussion

The values of monthly mean daily diffuse solar radiation intensity estimated using the above fourteen models (1–14) were compared with the corresponding measured values at the used eight stations. The relative percentage errors, *e(%)*, between the estimated and measured values of the monthly mean daily diffuse solar radiation intensity were determined using Eq. (20) for the 12 months of the year. The statistical tests of *MPE, MBE, RMSE, t-test,* and *NES* were also calculated using Eqs. (21–25), respectively. The results are given in *Tables 2–9*. Furthermore, *Table 10* summarizes the maximum and minimum values of the statistics errors, *MPE, MBE, RMSE, t-test,* and *NSE*, of each fourteen models at the eight selected stations.

It can be seen that the estimated values of D_c at each station are in favorable agreement with the measured values D_m for all the months of the year (*Tables 2–9*), whereas the percentage errors, *e(%),* for a single month not reaches ±10% for any of the locations. Based on all statistical test results of *MPE, MBE, RMSE, t-test,* and *NES* (*Tables 2–10*), all models are recommended for using to estimate the diffuse radiation at all stations, whereas all statistical test results are in the range of acceptable values between (–0.49 and +5.12) for *MPE*; (-0.39 and +2.78) for *MBE*; (+0.22 and +3.51) for *RMSE*; (+0.03 and +7.96) for *t-test*; and (0.9502 and 0.9999) for *NES*. On the other hand, it was found that the Tarhan and Sarı model, (Model 12), shows the best results among the all models for all of the stations. This is due to the fact that Model (12) has the lowest *MPE, MBE, RMSE,* and *t-test* value and highest *NES* values compared to the other fourteen models. It was found that, the overall percentage error, *e%*, of Model (12) is in the range of acceptable values between –5.04 and +3.31% with the lowest mean percentage error (*MPE*) values that range from –0.49% to +0.27%. Furthermore, 95.8% of these values *(e%)* lie between –2.64 and +2.94 for Model (12). Also, the *MBE* values of Model (12) are usually equal to zero or very close to zero, while the values of *t-test* range from +0.03 to 1.88. Furthermore, Model (12) has the highest values of *NES* and closest to 1.0, whereas they range from 0.9956 to 0.9999. These are considered excellent indicators in that the Tarhan and Sarı model (Model 12) gives precise estimation for each station and all Egypt with acceptable errors. Although Model (13) is almost like Model (12), Model (13) has higher values of *MPE, MBE, RMSE*, and *t-test* and lower values of *NES* than of Model (13), (See *Tables 2–9*). Therefore, it can be concluded that the Tarhan and Sarı model (Model 12) is extremely recommended for use to estimate diffuse solar radiation at any location in Egypt, i.e., Model (12) is the best model for estimating diffuse solar radiation on a horizontal surface over Egypt.

Table 2. Monthly mean values (1987–2016) of measured diffuse solar radiation, Dm (MJ.m^{-1}) and the corresponding calculated values, Dc (MJ.m^{-1}), that estimated using the different fourteen models in addition to the performance statistics errors (*MPE, MBE, RMSE, t-test* and *NSE*) at Sidi-Barrani

Month	***Dm* (1987-2016)**	**Model 1**		**Model 2**		**Model 3**		**Model 4**		**Model 5**		**Model 6**		**Model 7**		**Model 8**		**Model 9**		**Model 10**	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.89**	4.95	-1.27	4.98	-1.77	4.90	-0.23	4.89	0.02	5.24	-7.07	4.71	3.60	5.22	-6.73	4.95	-1.20	4.77	2.36	4.74	3.10
Feb	**6.05**	6.30	-4.15	6.29	-3.98	6.21	-2.67	6.15	-1.66	6.42	-6.13	6.13	-1.37	6.21	-2.63	6.27	-3.65	6.50	-7.37	6.30	-4.10
Mar	**8.11**	8.11	-0.02	7.91	2.49	7.86	3.04	7.52	7.27	7.78	4.12	7.69	5.21	7.92	2.31	7.94	2.06	8.59	-5.94	7.65	5.68
Apr	**9.75**	9.71	0.43	10.01	-2.68	9.35	4.10	8.91	8.58	9.04	7.28	8.95	8.17	9.15	6.11	9.45	3.12	9.70	0.47	8.91	8.62
May	**9.80**	9.80	0.01	10.05	-2.59	9.49	3.21	9.04	7.71	9.21	5.99	9.11	6.99	9.15	6.68	9.58	2.23	10.13	-3.39	9.08	7.32
Jun	**8.95**	8.90	0.57	8.80	1.71	8.65	3.39	8.31	7.18	8.32	7.09	8.14	9.08	8.45	5.59	8.73	2.41	9.16	-2.38	8.17	8.73
Jul	**9.11**	9.36	-2.71	9.52	-4.51	9.16	-0.50	8.91	2.21	8.80	3.38	8.78	3.64	8.99	1.27	9.24	-1.48	9.27	-1.80	8.58	5.83
Aug	**8.21**	8.37	-1.95	8.48	-3.25	8.21	-0.02	8.05	1.92	7.97	2.88	8.00	2.57	8.24	-0.35	8.29	-0.99	8.40	-2.36	7.78	5.21
Sep	**7.92**	8.05	-1.60	8.15	-2.85	7.89	0.39	7.74	2.32	7.71	2.71	7.69	2.85	7.96	-0.57	7.97	-0.59	8.10	-2.27	7.55	4.72
Oct	**6.38**	6.45	-1.10	6.50	-1.90	6.41	-0.53	6.41	-0.45	6.47	-1.47	6.28	1.57	6.55	-2.73	6.48	-1.50	6.58	-3.14	6.37	0.15
Nov	**5.32**	5.39	-1.39	5.23	1.73	5.34	-0.47	5.35	-0.50	5.49	-3.25	5.37	-0.87	5.49	-3.20	5.40	-1.44	5.62	-5.66	5.41	-1.72
Dec	**4.80**	4.83	-0.64	4.89	-1.94	4.74	1.25	4.65	3.13	5.01	-4.46	4.98	-3.66	4.86	-1.26	4.79	0.27	5.13	-6.88	4.79	0.25
MPE		–	0.59	–	3.24	–	-3.2	–	3.12	–	3.69	–	4.08	–	-2.23	–	0.08	–	-1.02	–	2.18
MBE		–	0.46	–	0.73	–	-0.58	–	0.84	–	0.91	–	0.73	–	0.29	–	0.12	–	0.05	–	0.73
RMS		–	0.98	–	0.85	–	0.71	–	1.63	–	1.54	–	1.58	–	0.78	–	0.46	–	0.79	–	1.34
t-test		–	3.14	–	2.99	–	5.99	–	3.05	–	3.49	–	2.96	–	2.75	–	0.11	–	0.19	–	3.69
NSE		–	0.983	–	0.966	–	0.970	–	0.9514	–	0.9502	–	0.9563	–	0.979	–	0.991	–	0.9812	–	0.970

Table 2. continued

Month	**Dm (1987-2016)**	Model 11		Model 12		Model 13		Model 14	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.89**	5.03	-2.83	5.02	-2.64	5.29	-8.17	4.88	0.23
Feb	**6.05**	5.68	6.04	6.34	-4.74	6.18	-2.21	6.14	-1.45
Mar	**8.11**	8.40	-3.55	8.00	1.39	8.02	1.08	7.50	7.48
Apr	**9.75**	10.11	-3.74	9.48	2.77	9.19	5.72	8.80	9.79
May	**9.80**	10.16	-3.65	9.59	2.16	9.01	8.05	9.02	7.92
Jun	**8.95**	9.20	-2.77	8.65	3.31	8.61	3.77	8.29	7.39
Jul	**9.11**	9.62	-5.57	9.07	0.46	9.06	0.58	8.89	2.42
Aug	**8.21**	8.56	-4.31	8.15	0.78	8.34	-1.59	8.04	2.13
Sep	**7.92**	8.23	-3.91	7.86	0.73	8.10	-2.30	7.72	2.53
Oct	**6.38**	6.57	-2.96	6.45	-1.08	6.72	-5.34	6.40	-0.24
Nov	**5.32**	5.47	-2.79	5.42	-1.93	5.52	-3.84	5.34	-0.29
Dec	**4.80**	4.94	-3.00	4.85	-1.05	4.66	2.82	4.64	3.34

MPE			-3.98	–	0.07	–	0.12	–	2.35
MBE			-0.88	–	0.00	–	0.23	–	0.82
RMSE			0.89	–	0.33	–	0.54	–	1.23
t-test			7.96	–	0.03	–	0.26	–	2.96
NSE			0.9729	–	**0.9999**	–	0.9899	–	0.9679

Table 3. The same as *Table 2*, but for Matruh

Month	*Dm* (1987-2016)	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7		Model 8		Model 9		Model 10	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.28**	4.29	-0.23	4.33	-1.27	3.98	7.07	4.44	-3.65	4.51	-5.36	4.19	2.05	4.08	4.63	4.11	3.98	4.15	3.14	4.31	-0.70
Feb	**5.91**	5.75	2.67	6.16	-4.15	6.27	-6.13	6.17	-4.40	6.22	-5.27	5.93	-0.37	5.82	1.44	5.94	-0.44	5.96	-0.77	5.97	-1.09
Mar	**8.35**	8.10	3.04	8.35	-0.02	8.01	4.12	8.05	3.58	8.03	3.85	7.92	5.14	8.16	2.23	8.48	-1.50	8.21	1.65	7.95	4.80
Apr	**9.33**	8.95	4.10	9.29	0.43	8.65	7.28	8.80	5.69	8.72	6.49	9.03	3.25	9.14	1.99	9.30	0.34	9.06	2.92	8.82	5.49
May	**10.12**	9.80	3.21	10.12	0.01	9.51	5.99	9.65	4.60	9.58	5.30	9.32	7.93	9.83	2.84	10.34	-2.21	10.1	-0.20	9.94	1.80
Jun	**9.43**	9.11	3.39	9.38	0.57	8.76	7.09	8.94	5.24	8.85	6.16	8.90	5.67	9.19	2.50	9.42	0.16	9.17	2.71	8.93	5.27
Jul	**9.83**	9.88	-0.50	10.10	-2.71	9.50	3.38	9.69	1.44	9.59	2.41	9.68	1.56	9.62	2.18	9.81	0.17	9.56	2.75	9.31	5.34
Aug	**8.72**	8.72	-0.02	8.89	-1.95	8.47	2.88	8.60	1.43	8.53	2.16	8.57	1.67	8.54	2.05	8.70	0.18	8.52	2.27	8.34	4.37
Sep	**7.98**	7.95	0.40	8.11	-1.60	7.76	2.71	7.86	1.55	7.81	2.13	8.03	-0.57	7.90	0.96	8.08	-1.32	7.90	1.02	7.71	3.35
Oct	**6.48**	6.51	-0.53	6.55	-1.10	6.58	-1.47	6.54	-1.00	6.56	-1.23	6.86	-5.88	6.81	-5.14	6.69	-3.25	6.61	-1.98	6.53	-0.71
Nov	**5.22**	5.20	0.47	5.29	-1.39	5.39	-3.25	5.32	-1.86	5.35	-2.55	5.01	4.08	5.07	2.78	5.32	-1.93	5.26	-0.86	5.21	0.21
Dec	**4.46**	4.40	1.25	4.49	-0.64	4.66	-4.46	4.39	1.61	4.32	3.03	4.29	3.74	4.24	4.85	4.35	2.44	4.36	2.18	4.37	1.91
MPE		–	0.98	–	5.12	–	1.84	–	2.93	–	3.95	–	1.28	–	-1.72	–	0.23	–	0.37	–	-1.29
MBE		–	1.63	–	2.78	–	-0.75	–	1.09	–	2.07	–	-0.21	–	1.14	–	-0.25	–	1.32	–	-0.81
RMSE		–	2.06	–	1.96	–	0.96	–	3.51	–	0.13	–	0.59	–	1.19	–	0.51	–	0.65	–	0.98
t-test		–	4.19	–	5.74	–	2.75	–	4.32	–	5.32	–	3.23	–	0.79	–	0.81	–	0.79	–	2.05
NSE		–	0.979	–	0.960	–	0.980	–	0.9588	–	0.9609	–	0.9781	–	0.969	–	0.989	–	0.9748	–	0.977

Table 3. continued

Month	***Dm* (1987-2016)**	**Model 11**		**Model 12**		**Model 13**		**Model 14**	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.28**	4.23	1.22	4.27	0.26	4.23	1.10	4.19	2.18
Feb	**5.91**	5.96	-0.93	6.03	-2.01	5.95	-0.68	5.96	-0.85
Mar	**8.35**	8.08	3.23	8.77	-5.01	8.28	0.86	8.15	2.44
Apr	**9.33**	8.94	4.20	9.16	1.85	9.12	2.27	9.00	3.56
May	**10.12**	10.04	0.80	9.99	1.30	10.19	-0.70	10.09	0.30
Jun	**9.43**	9.05	3.99	9.37	0.63	9.23	2.07	9.11	3.35
Jul	**9.83**	9.43	4.05	9.71	1.19	9.62	2.11	9.50	3.40
Aug	**8.72**	8.43	3.32	8.65	0.85	8.57	1.75	8.48	2.80
Sep	**7.98**	7.81	2.18	7.76	2.77	7.95	0.43	7.85	1.60
Oct	**6.48**	6.57	-1.34	6.61	-2.03	6.63	-2.30	6.59	-1.66
Nov	**5.22**	5.24	-0.32	5.22	-0.06	5.28	-1.12	5.25	-0.59
Dec	**4.46**	4.37	2.04	4.42	0.98	4.40	1.24	4.37	2.11
MPE		–	2.60	–	0.11	–	0.42	–	2.07
MBE		–	0.79	–	-0.04	–	0.33	–	-0.82
RMSE		–	0.88	–	0.32	–	0.59	–	1.06
t-test		–	3.11	–	0.15	–	0.96	–	2.68
NSE		–	0.9806	–	0.9996	–	0.9889	–	0.9663

Table 4. The same as *Table 2*, but for El-Arich

Month	Dm (1987-2016)	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7		Model 8		Model 9		Model 10	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.88**	4.90	-0.34	4.95	-1.34	4.54	6.90	5.05	-3.38	5.09	-4.34	4.83	0.95	4.62	5.23	4.64	4.87	4.67	4.20	4.87	0.27
Feb	**6.73**	6.56	2.56	7.01	-4.22	7.15	-6.30	7.01	-4.14	7.02	-4.24	6.83	-1.48	6.59	2.04	6.63	1.54	6.71	0.30	6.74	-0.12
Mar	**8.96**	8.70	2.93	8.97	-0.09	8.61	3.95	8.62	3.85	8.52	4.87	8.60	4.03	8.71	2.83	9.10	-1.60	8.72	2.72	8.44	5.77
Apr	**9.79**	9.40	3.99	9.76	0.36	9.09	7.11	9.21	5.96	9.05	7.51	9.58	2.15	9.54	2.59	9.79	0.04	9.40	3.98	9.16	6.46
May	**10.19**	9.87	3.10	10.20	-0.06	9.60	5.82	9.69	4.87	9.55	6.32	9.49	6.83	9.84	3.44	10.37	-1.81	10.1	0.86	9.91	2.77
Jun	**10.01**	9.68	3.28	9.96	0.50	9.32	6.92	9.46	5.50	9.29	7.19	9.55	4.56	9.70	3.10	10.00	0.05	9.63	3.78	9.39	6.24
Jul	**9.52**	9.58	-0.61	9.78	-2.78	9.21	3.21	9.36	1.71	9.19	3.43	9.48	0.45	9.26	2.78	9.51	0.07	9.16	3.82	8.92	6.31
Aug	**9.08**	9.09	-0.13	9.26	-2.02	8.83	2.71	8.93	1.70	8.79	3.18	9.03	0.56	8.84	2.65	9.07	0.06	8.78	3.34	8.60	5.34
Sep	**9.31**	9.28	0.29	9.47	-1.67	9.07	2.54	9.14	1.81	9.02	3.15	9.47	-1.67	9.16	1.56	9.44	-1.42	9.12	2.08	8.91	4.32
Oct	**7.04**	7.08	-0.64	7.12	-1.17	7.16	-1.64	7.09	-0.73	7.05	-0.21	7.53	-6.98	7.36	-4.54	7.28	-1.03	7.10	-0.91	7.02	0.26
Nov	**6.15**	6.13	0.36	6.24	-1.46	6.36	-3.42	6.25	-1.59	6.24	-1.53	5.97	2.97	5.94	3.38	6.21	-3.35	6.14	0.21	6.08	1.18
Dec	**4.81**	4.76	1.14	4.84	-0.71	5.03	-4.63	4.72	1.87	4.61	4.06	4.68	2.64	4.55	5.45	4.66	3.04	4.65	3.24	4.67	2.88
MPE		–	1.05		1.19		1.40		1.99		-2.37		1.37		2.73		0.36		2.13		-2.11
MBE		–	0.82		2.11		1.42		1.37		0.91		1.32		2.27		-0.16		1.19		-0.93
RMSE		–	1.38		2.73		2.64		3.43		1.92		1.65		0.53		0.73		1.53		1.02
t-test		–	1.86		1.76		1.68		1.58		2.35		3.79		4.71		1.01		3.95		4.07
NSE		–	0.977		0.985		0.979		0.9868		0.9731		0.9648		0.960		0.990		0.9726		0.962

Table 4. continued

Month	**Dm (1987-2016)**	Model 11		Model 12		Model 13		Model 14	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.88**	4.77	2.18	4.98	-2.03	4.91	-0.71	4.92	-0.87
Feb	**6.73**	6.71	0.24	6.71	0.24	6.73	0.07	6.58	2.16
Mar	**8.96**	8.58	4.29	9.41	-5.04	8.88	0.84	8.74	2.41
Apr	**9.79**	9.37	4.27	9.61	1.82	9.57	2.25	9.44	3.54
May	**10.19**	10.00	1.86	10.06	1.28	10.26	-0.73	10.16	0.27
Jun	**10.01**	9.50	5.06	9.95	0.61	9.80	2.05	9.68	3.33
Jul	**9.52**	9.03	5.11	9.44	0.82	9.48	0.41	9.37	1.58
Aug	**9.08**	8.68	4.39	8.85	2.54	8.89	2.08	8.77	3.38
Sep	**9.31**	9.01	3.25	9.20	1.17	9.15	1.73	9.05	2.77
Oct	**7.04**	7.06	-0.28	7.18	-2.05	7.20	-2.32	7.16	-1.68
Nov	**6.15**	6.10	0.74	6.09	0.95	6.08	1.22	6.02	2.09
Dec	**4.81**	4.66	3.11	4.81	-0.08	4.87	-1.15	4.84	-0.61
MPE		–	2.99	–	-0.08	–	0.31	–	-1.33
MBE		–	1.11	–	0.13	–	0.28	–	-0.91
RMSE		–	1.88	–	0.22	–	0.49	–	0.84
t-test		–	5.78	–	0.19	–	1.03	–	2.45
NSE		–	0.9596	–	0.9997	–	0.9923	–	0.9744

Table 5. The same as *Table 2*, but for Tahrir

Month	*Dm (1987-2016)*	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7		Model 8		Model 9		Model 10	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.79**	4.75	0.84	4.89	-2.09	4.60	3.87	4.99	-4.25	4.87	-1.69	4.64	3.09	4.55	5.05	4.88	-1.88	4.71	1.67	4.73	1.22
Feb	**6.06**	6.01	0.83	6.27	-3.53	6.26	-3.35	6.25	-3.13	6.23	-2.86	6.04	0.28	5.95	1.79	5.99	1.11	5.99	1.23	6.06	0.06
Mar	**8.83**	8.70	1.42	8.77	0.66	8.48	3.95	8.58	2.84	8.44	4.45	8.53	3.43	8.78	0.62	8.72	1.28	8.60	2.57	8.39	5.03
Apr	**9.70**	9.49	2.17	9.82	-1.27	9.01	7.11	9.11	6.06	9.23	4.83	9.47	2.37	9.57	1.31	9.42	2.89	9.34	3.76	9.18	5.36
May	**9.69**	9.54	1.52	9.62	0.73	9.13	5.82	9.22	4.80	9.05	6.57	9.19	5.13	9.61	0.81	9.71	-0.23	9.63	0.57	9.47	2.31
Jun	**9.02**	8.85	1.89	8.91	1.19	8.40	6.92	8.64	4.25	8.49	5.88	8.67	3.83	8.88	1.58	8.78	2.69	8.70	3.55	8.51	5.65
Jul	**8.60**	8.45	1.69	8.79	-2.24	8.32	3.21	8.41	2.21	8.43	1.94	8.46	1.62	8.48	1.43	8.69	-0.99	8.37	2.70	8.11	5.71
Aug	**8.35**	8.26	1.07	8.48	-1.55	8.12	2.71	8.04	3.70	8.19	1.87	8.22	1.61	8.24	1.36	8.12	2.73	8.07	3.36	7.94	4.86
Sep	**8.13**	8.07	0.69	8.23	-1.18	7.92	2.54	7.80	4.00	8.07	0.74	8.13	-0.06	8.12	0.07	7.95	2.25	7.93	2.43	7.82	3.78
Oct	**6.47**	6.41	0.90	6.54	-1.04	6.58	-1.64	6.53	-0.93	6.70	-3.60	6.84	-5.76	6.65	-2.79	6.60	-2.00	6.55	-1.30	6.47	-0.01
Nov	**5.31**	5.28	0.55	5.36	-1.01	5.49	-3.42	5.46	-2.78	5.27	0.72	5.14	3.18	5.31	0.02	5.22	1.65	5.25	1.15	5.26	0.96
Dec	**4.55**	4.54	0.21	4.54	0.25	4.69	-3.13	4.37	3.98	4.40	3.35	4.37	4.05	4.36	4.24	4.59	-0.88	4.49	1.31	4.41	2.99
MPE		–	1.23	–	1.59	–	-0.71	–	1.68	–	0.18	–	0.865	–	2.43	–	-0.88	–	2.56	–	-1.10
MBE		–	1.12	–	1.74	–	1.16	–	1.34	–	1.59	–	0.58	–	1.73	–	-0.54	–	1.15	–	-0.40
RMSE		–	2.01	–	3.08	–	2.28	–	2.54	–	1.23	–	1.19	–	1.03	–	0.88	–	1.705	–	0.62
t-test		–	1.77	–	1.67	–	2.01	–	2.69	–	3.53	–	2.4	–	4.33	–	1.54	–	4.865	–	2.13
NSE		–	0.978	–	0.986	–	0.976	–	0.9758	–	0.9670	–	0.9775	–	0.9667	–	0.998	–	0.9661	–	0.981

Table 5. continued

Month	**Dm (1987-2016)**	**Model 11**		**Model 12**		**Model 13**		**Model 14**	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.79**	4.79	0.08	4.86	-1.37	4.67	2.54	4.70	1.83
Feb	**6.06**	6.05	0.24	6.05	0.16	6.00	0.92	5.97	1.54
Mar	**8.83**	8.86	-0.37	9.02	-2.10	8.78	0.56	8.70	1.49
Apr	**9.70**	9.40	3.05	9.50	2.04	9.51	2.01	9.43	2.77
May	**9.69**	9.54	1.57	9.66	0.27	9.74	-0.47	9.70	-0.10
Jun	**9.02**	8.76	2.83	8.90	1.33	8.85	1.92	8.78	2.62
Jul	**8.60**	8.34	2.97	8.55	0.62	8.43	1.95	8.45	1.76
Aug	**8.35**	8.06	3.47	8.16	2.31	8.21	1.70	8.14	2.54
Sep	**8.13**	7.95	2.21	8.01	1.45	8.10	0.33	8.00	1.55
Oct	**6.47**	6.55	-1.16	6.61	-2.18	6.57	-0.97	6.56	-1.33
Nov	**5.31**	5.27	0.85	5.25	1.09	5.36	-1.57	5.30	0.26
Dec	**4.55**	4.48	1.51	4.58	-0.61	4.41	3.14	4.49	1.26
MPE		–	0.98	–	-0.49	–	0.98	–	0.55
MBE		–	0.49	–	-0.39	–	-0.83	–	0.41
RMSE		–	0.84	–	0.53	–	1.06	–	0.94
t-test		–	2.22	–	0.32	–	1.79	–	3.39
NSE		–	0.9841	–	0.9993	–	0.9958	–	0.9706

Table 6. The same as *Table 2*, but for Cairo

Month	*Dm (1987-2016)*	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7		Model 8		Model 9		Model 10	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.50**	4.39	2.35	4.64	-3.17	4.45	1.09	4.53	-0.58	4.42	1.68	4.47	0.60	4.35	3.36	4.51	-0.33	4.46	0.87	4.50	-0.07
Feb	**5.90**	5.97	-1.26	6.10	-3.33	6.08	-3.10	5.98	-1.42	5.93	-0.53	5.86	0.70	5.81	1.51	5.87	0.59	5.86	0.73	5.89	0.11
Mar	**7.60**	7.40	2.68	7.47	1.75	7.28	4.20	7.36	3.14	7.41	2.53	7.42	2.35	7.48	1.59	7.36	3.15	7.52	1.10	7.49	1.47
Apr	**8.30**	7.91	4.64	8.10	2.39	7.80	5.97	7.95	4.21	8.05	3.07	8.08	2.63	8.09	2.54	7.96	4.13	8.02	3.40	7.99	3.70
May	**9.30**	8.96	3.67	9.04	2.76	8.72	6.20	8.84	4.97	8.96	3.69	9.07	2.45	9.24	0.69	9.20	1.04	9.20	1.07	9.18	1.29
Jun	**9.00**	8.60	4.40	8.76	2.72	8.42	6.40	8.64	4.04	8.66	3.73	8.71	3.26	8.77	2.57	8.62	4.17	8.71	3.19	8.69	3.49
Jul	**8.50**	8.29	2.45	8.50	-0.01	8.28	2.57	8.34	1.91	8.36	1.69	8.47	0.31	8.32	2.06	8.30	2.36	8.26	2.83	8.23	3.16
Aug	**8.40**	8.24	1.89	8.31	1.07	8.21	2.29	8.18	2.65	8.26	1.62	8.22	2.17	8.20	2.36	8.08	3.80	8.11	3.41	8.10	3.59
Sep	**8.10**	7.97	1.61	7.99	1.41	7.97	1.64	7.94	1.97	8.07	0.40	8.01	1.10	8.00	1.25	7.86	3.02	7.91	2.32	7.89	2.62
Oct	**6.10**	6.12	-0.37	6.16	-0.99	6.26	-2.62	6.30	-3.35	6.29	-3.19	6.34	-3.88	6.22	-2.04	6.16	-1.01	6.18	-1.23	6.17	-1.10
Nov	**5.60**	5.68	-1.43	5.71	-1.89	5.68	-1.35	5.59	0.20	5.58	0.37	5.46	2.42	5.57	0.58	5.53	1.31	5.54	1.00	5.54	1.02
Dec	**4.60**	4.67	-1.46	4.50	2.12	4.59	0.11	4.42	4.01	4.43	3.80	4.53	1.58	4.47	2.78	4.55	1.06	4.53	1.41	4.55	1.19
MPE		–	1.45	–	0.88	–	0.19	–	2.05	–	-0.35	–	1.71	–	0.67	–	0.05	–	0.93	–	-0.06
MBE		–	1.23	–	1.66	–	0.87	–	1.54	–	0.52	–	0.87	–	0.67	–	-0.03	–	0.38	–	-0.62
RMS		–	2.27	–	2.15	–	1.73	–	1.79	–	1.05	–	1.45	–	0.83	–	0.56	–	1.12	–	0.84
t-test		–	2.23	–	2.60	–	2.21	–	3.51	–	2.53	–	3.63	–	3.23	–	1.88	–	2.59	–	1.96
NSE		–	0.977	–	0.976	–	0.976	–	0.9713	–	0.9828	–	0.9718	–	0.9740	–	0.996	–	0.9827	–	0.988

Table 6. continued

Month	***Dm (1987-2016)***	**Model 11**		**Model 12**		**Model 13**		**Model 14**	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.50**	4.44	1.31	4.49	0.23	4.42	1.70	4.43	1.57
Feb	**5.90**	5.87	0.58	5.85	0.85	5.85	0.83	5.84	1.06
Mar	**7.60**	7.59	0.09	7.62	-0.31	7.54	0.83	7.54	0.79
Apr	**8.30**	8.09	2.53	8.10	2.40	8.08	2.71	8.08	2.65
May	**9.30**	9.25	0.55	9.29	0.09	9.27	0.30	9.28	0.22
Jun	**9.00**	8.79	2.37	8.82	1.98	8.77	2.55	8.78	2.50
Jul	**8.50**	8.29	2.46	8.40	1.19	8.30	2.39	8.32	2.11
Aug	**8.40**	8.18	2.58	8.20	2.43	8.19	2.56	8.18	2.56
Sep	**8.10**	8.00	1.27	7.98	1.50	7.99	1.33	7.99	1.41
Oct	**6.10**	6.17	-1.07	6.21	-1.76	6.12	-1.10	6.17	-1.20
Nov	**5.60**	5.62	-0.36	5.56	0.67	5.66	-0.29	5.60	-0.05
Dec	**4.60**	4.49	2.33	4.59	0.32	4.50	2.28	4.52	1.79
MPE		–	0.77	–	-0.04	–	0.16	–	0.74
MBE		–	0.45	–	0.01	–	0.24	–	0.40
RMSE		–	0.89	–	0.33	–	0.68	–	1.03
t-test		–	2.80	–	0.86	–	1.92	–	2.99
NSE		–	0.9774	–	0.9999	–	0.9927	–	0.9766

*Table 7.*The same as *Table 2,* but for El-Kgarga

Month	*Dm (1987-2016)*	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7		Model 8		Model 9		Model 10	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.50**	4.46	0.89	4.53	-0.75	4.46	0.85	4.44	1.39	4.47	0.67	4.47	0.74	4.43	1.64	4.48	0.49	4.48	0.55	4.47	0.75
Feb	**5.44**	5.51	-1.34	5.55	-1.93	5.51	-1.20	5.44	0.04	5.44	0.03	5.40	0.72	5.40	0.81	5.41	0.58	5.40	0.79	5.41	0.58
Mar	**7.42**	7.20	2.91	7.26	2.14	7.18	3.28	7.24	2.36	7.21	2.84	7.29	1.73	7.31	1.53	7.30	1.62	7.39	0.40	7.34	1.13
Apr	**8.29**	7.92	4.43	8.06	2.73	7.93	4.30	8.01	3.37	7.99	3.60	8.04	3.02	8.03	3.12	8.01	3.33	8.05	2.90	8.03	3.17
May	**8.65**	8.28	4.32	8.37	3.23	8.28	4.32	8.41	2.83	8.45	2.37	8.50	1.76	8.56	0.99	8.58	0.80	8.60	0.58	8.58	0.76
Jun	**8.20**	7.85	4.22	7.94	3.22	7.80	4.83	7.93	3.30	7.88	3.95	7.94	3.23	7.95	3.03	7.93	3.27	7.99	2.58	7.95	2.99
Jul	**7.81**	7.64	2.18	7.74	0.84	7.70	1.44	7.65	1.99	7.65	2.02	7.69	1.57	7.61	2.61	7.62	2.41	7.65	2.01	7.60	2.64
Aug	**7.78**	7.60	2.27	7.68	1.34	7.61	2.23	7.59	2.51	7.57	2.71	7.56	2.79	7.55	2.97	7.53	3.19	7.55	2.92	7.54	3.07
Sep	**7.89**	7.75	1.79	7.82	0.91	7.78	1.37	7.76	1.61	7.76	1.71	7.76	1.71	7.74	1.93	7.72	2.14	7.74	1.91	7.73	2.01
Oct	**5.61**	5.71	-1.86	5.73	-2.09	5.79	-3.25	5.76	-2.69	5.73	-2.10	5.75	-2.56	5.70	-1.57	5.67	-1.04	5.69	-1.49	5.67	-1.15
Nov	**4.59**	4.62	-0.62	4.63	-0.76	4.57	0.53	4.57	0.39	4.55	0.84	4.51	1.71	4.55	0.80	4.57	0.47	4.55	0.83	4.57	0.48
Dec	**4.20**	4.15	1.28	4.08	2.96	4.16	0.85	4.06	3.40	4.10	2.43	4.14	1.50	4.12	1.98	4.13	1.69	4.16	0.87	4.14	1.49
MPE		–	1.75	–	0.41	–	0.95	–	1.36	–	-0.15	–	1.32	–	0.52	–	0.27	–	0.43	–	0.34
MBE		–	1.38	–	1.09	–	0.87	–	1.10	–	0.43	–	0.62	–	0.02	–	0.21	–	0.49	–	-0.11
RMS		–	2.03	–	1.60	–	1.59	–	1.31	–	0.95	–	1.28	–	0.83	–	0.72	–	0.87	–	0.93
t-test		–	2.87	–	2.57	–	2.92	–	3.37	–	2.21	–	3.11	–	2.59	–	1.72	–	2.24	–	2.37
NSE		–	0.974	–	0.979	–	0.974	–	0.9727	–	0.9895	–	0.9772	–	0.9813	–	0.991	–	0.9889	–	0.982

Table 7. continued

Month	***Dm (1987-2016)***	**Model 11**		**Model 12**		**Model 13**		**Model 14**	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.50**	4.43	1.51	4.48	0.36	4.45	1.13	4.45	1.16
Feb	**5.44**	5.40	0.70	5.40	0.71	5.40	0.81	5.40	0.82
Mar	**7.42**	7.39	0.46	7.37	0.66	7.37	0.61	7.35	0.96
Apr	**8.29**	8.07	2.62	8.05	2.87	8.06	2.80	8.05	2.91
May	**8.65**	8.61	0.42	8.61	0.44	8.61	0.44	8.61	0.49
Jun	**8.20**	8.00	2.46	7.98	2.62	7.99	2.57	7.97	2.75
Jul	**7.81**	7.62	2.42	7.67	1.80	7.64	2.20	7.62	2.37
Aug	**7.78**	7.58	2.57	7.56	2.81	7.57	2.74	7.56	2.82
Sep	**7.89**	7.79	1.30	7.75	1.82	7.76	1.62	7.75	1.71
Oct	**5.61**	5.67	-1.08	5.69	-1.40	5.59	-1.30	5.68	-1.17
Nov	**4.59**	4.60	-0.32	4.56	0.57	4.65	0.27	4.58	0.22
Dec	**4.20**	4.10	2.30	4.16	1.01	4.13	1.57	4.13	1.64
MPE		–	0.69	–	0.13	–	0.32	–	0.54
MBE		–	0.53	–	0.11	–	0.37	–	0.14
RMSE		–	0.98	–	0.58	–	0.90	–	0.98
t-test		–	3.06	–	1.60	–	1.98	–	2.73
NSE		–	0.9850	–	0.9956	–	0.9897	–	0.9796

Table 8. The same as *Table 2*, but for Qena

Month	*Dm (1987-2016)*	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7		Model 8		Model 9		Model 10	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.53**	4.48	1.14	4.52	0.32	4.50	0.76	4.46	1.52	4.51	0.58	4.50	0.64	4.48	1.10	4.51	0.42	4.49	1.03	4.47	1.32
Feb	**4.79**	4.82	-0.65	4.83	-0.94	4.82	-0.59	4.77	0.43	4.77	0.30	4.75	0.75	4.75	0.80	4.76	0.65	4.75	0.75	4.75	0.76
Mar	**6.41**	6.24	2.64	6.26	2.25	6.21	3.06	6.28	1.95	6.27	2.23	6.34	1.06	6.35	0.96	6.34	1.14	6.38	0.43	6.37	0.54
Apr	**7.16**	6.88	3.90	6.94	3.05	6.87	3.95	6.92	3.25	6.91	3.46	6.94	2.96	6.94	3.01	6.93	3.10	6.96	2.76	6.96	2.71
May	**8.73**	8.42	3.57	8.46	3.03	8.44	3.35	8.56	1.91	8.59	1.58	8.63	1.17	8.66	0.79	8.67	0.62	8.69	0.50	8.69	0.43
Jun	**8.38**	8.06	3.76	8.10	3.26	8.01	4.39	8.11	3.17	8.07	3.61	8.13	2.91	8.14	2.81	8.13	2.95	8.17	2.52	8.17	2.52
Jul	**6.91**	6.77	2.09	6.82	1.41	6.79	1.73	6.75	2.30	6.76	2.21	6.79	1.79	6.75	2.31	6.77	2.10	6.76	2.22	6.75	2.31
Aug	**6.31**	6.16	2.39	6.18	1.93	6.15	2.47	6.13	2.74	6.12	2.95	6.13	2.85	6.12	2.95	6.12	3.00	6.13	2.74	6.14	2.65
Sep	**6.80**	6.68	1.70	6.71	1.26	6.69	1.54	6.68	1.77	6.67	1.93	6.67	1.81	6.67	1.92	6.66	1.98	6.69	1.60	6.70	1.46
Oct	**5.17**	5.29	-2.28	5.29	-2.39	5.31	-2.67	5.28	-2.13	5.25	-1.57	5.27	-2.03	5.25	-1.53	5.23	-1.22	5.23	-1.29	5.23	-1.19
Nov	**4.67**	4.67	-0.11	4.68	-0.19	4.64	0.68	4.64	0.60	4.64	0.65	4.61	1.27	4.63	0.82	4.64	0.52	4.66	0.25	4.67	-0.03
Dec	**4.16**	4.06	2.34	4.02	3.18	4.09	1.64	4.05	2.69	4.07	2.06	4.11	1.18	4.10	1.43	4.10	1.35	4.09	1.59	4.08	1.94
MPE		–	1.56	–	0.81	–	0.40	–	0.83	–	0.13	–	0.87	–	0.37	–	0.29	–	0.56	–	0.60
MBE		–	1.24	–	1.10	–	0.56	–	0.56	–	0.23	–	0.41	–	0.11	–	0.16	–	0.34	–	0.43
RMS		–	1.67	–	1.45	–	1.27	–	1.07	–	0.91	–	1.00	–	0.78	–	0.73	–	0.85	–	0.94
t-test		–	3.12	–	2.97	–	2.56	–	2.98	–	2.27	–	2.42	–	2.16	–	1.97	–	2.39	–	2.79
NSE		–	0.973	–	0.976	–	0.981	–	0.9770	–	0.9804	–	0.9843	–	0.9863	–	0.993	–	0.9881	–	0.9874

Table 8. continued

Month	**Dm (1987-2016)**	**Model 11**		**Model 12**		**Model 13**		**Model 14**	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.53**	4.50	0.76	4.50	0.73	4.48	1.22	4.49	0.90
Feb	**4.79**	4.75	0.77	4.75	0.76	4.75	0.78	4.75	0.79
Mar	**6.41**	6.36	0.81	6.36	0.81	6.37	0.57	6.34	1.01
Apr	**7.16**	6.95	2.89	6.95	2.94	6.96	2.76	6.95	2.94
May	**8.73**	8.69	0.47	8.68	0.61	8.69	0.43	8.66	0.83
Jun	**8.38**	8.15	2.68	8.15	2.71	8.16	2.54	8.14	2.83
Jul	**6.91**	6.77	2.09	6.77	2.05	6.76	2.26	6.77	2.08
Aug	**6.31**	6.13	2.81	6.12	2.88	6.14	2.70	6.13	2.84
Sep	**6.80**	6.68	1.77	6.67	1.87	6.69	1.54	6.68	1.76
Oct	**5.17**	5.23	-1.28	5.24	-1.46	5.16	-1.24	5.25	-1.60
Nov	**4.67**	4.65	0.39	4.64	0.69	4.73	0.12	4.63	0.74
Dec	**4.16**	4.10	1.33	4.11	1.22	4.08	1.75	4.10	1.41
MPE		–	0.35	–	0.27	–	0.56	–	0.71
MBE		–	0.13	–	0.11	–	0.40	–	0.28
RMSE		–	0.78	–	0.68	–	0.92	–	0.99
t-test		–	2.17	–	1.88	–	2.65	–	2.58
NSE		–	0.9876	–	0.9987	–	0.9896	–	0.9819

Table 9. The same as *Table 2*, but for Aswan

Month	*Dm (1987-2016)*	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7		Model 8		Model 9		Model 10	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.78**	4.73	0.95	4.76	0.45	4.75	0.67	4.72	1.31	4.74	0.84	4.74	0.84	4.74	0.93	4.74	0.87	4.74	0.89	4.73	1.02
Feb	**5.64**	5.67	-0.62	5.66	-0.32	5.65	-0.14	5.61	0.61	5.61	0.55	5.60	0.75	5.60	0.78	5.60	0.70	5.60	0.76	5.60	0.76
Mar	**7.20**	6.99	2.85	7.04	2.24	7.01	2.65	7.10	1.45	7.09	1.60	7.15	0.74	7.14	0.88	7.14	0.84	7.16	0.62	7.15	0.67
Apr	**7.96**	7.65	3.92	7.70	3.26	7.66	3.71	7.71	3.13	7.70	3.24	7.73	2.86	7.73	2.95	7.73	2.90	7.74	2.82	7.74	2.82
May	**8.61**	8.31	3.46	8.41	2.31	8.40	2.46	8.49	1.35	8.51	1.18	8.54	0.83	8.56	0.63	8.56	0.52	8.57	0.48	8.57	0.52
Jun	**8.90**	8.54	4.08	8.59	3.44	8.54	4.00	8.63	2.99	8.61	3.21	8.66	2.72	8.66	2.75	8.66	2.73	8.67	2.60	8.67	2.62
Jul	**8.11**	7.96	1.91	7.96	1.81	7.95	1.97	7.92	2.31	7.93	2.26	7.95	2.00	7.93	2.20	7.93	2.21	7.94	2.15	7.93	2.18
Aug	**8.12**	7.92	2.43	7.92	2.44	7.90	2.71	7.89	2.84	7.88	2.95	7.89	2.80	7.89	2.88	7.89	2.83	7.89	2.78	7.90	2.77
Sep	**7.67**	7.55	1.62	7.55	1.59	7.54	1.73	7.53	1.85	7.52	1.92	7.54	1.71	7.53	1.84	7.54	1.72	7.54	1.69	7.54	1.66
Oct	**6.21**	6.36	-2.48	6.33	-1.98	6.34	-2.12	6.32	-1.83	6.31	-1.55	6.31	-1.66	6.30	-1.41	6.28	-1.20	6.29	-1.29	6.29	-1.33
Nov	**5.33**	5.31	0.29	5.32	0.23	5.29	0.67	5.29	0.71	5.29	0.74	5.29	0.76	5.30	0.61	5.32	0.25	5.31	0.32	5.31	0.33
Dec	**4.41**	4.32	1.99	4.29	2.62	4.33	1.85	4.32	2.06	4.33	1.74	4.35	1.38	4.35	1.38	4.34	1.64	4.35	1.46	4.34	1.58
MPE		–	0.98	–	0.47	–	0.27	–	0.60	–	0.25	–	0.71	–	0.36	–	0.94	–	0.45	–	0.43
MBE		–	0.90	–	0.66	–	0.39	–	0.34	–	0.17	–	0.38	–	0.12	–	0.23	–	0.24	–	0.27
RMS		–	1.47	–	1.18	–	1.09	–	0.92	–	0.84	–	0.93	–	0.78	–	0.83	–	0.82	–	0.81
t-test		–	2.84	–	2.62	–	2.42	–	2.57	–	2.22	–	2.40	–	2.16	–	1.81	–	2.28	–	2.33
NSE		–	0.983	–	0.978	–	0.981	–	0.9816	–	0.9834	–	0.9862	–	0.9870	–	0.996	–	0.9879	–	0.993

Table 9. continued

Month	***Dm (1987-2016)***	**Model 11**		**Model 12**		**Model 13**		**Model 14**	
		Dc	*e%*	*Dc*	*e%*	*Dc*	*e%*	*Dc*	*e%*
Jan	**4.78**	4.74	0.83	4.74	0.92	4.74	0.84	4.73	1.10
Feb	**5.64**	5.60	0.78	5.60	0.78	5.63	0.23	5.60	0.70
Mar	**7.20**	7.13	0.91	7.13	0.95	7.10	1.41	7.11	1.23
Apr	**7.96**	7.73	2.91	7.73	2.94	7.72	3.01	7.72	3.03
May	**8.61**	8.55	0.65	8.55	0.73	8.49	1.37	8.52	1.09
Jun	**8.90**	8.65	2.76	8.65	2.79	8.63	2.99	8.64	2.91
Jul	**8.11**	7.94	2.08	7.94	2.14	7.95	2.03	7.93	2.19
Aug	**8.12**	7.89	2.82	7.89	2.86	7.91	2.57	7.89	2.84
Sep	**7.67**	7.53	1.76	7.53	1.80	7.55	1.57	7.53	1.80
Oct	**6.21**	6.30	-1.44	6.30	-1.50	6.20	-1.61	6.32	-1.72
Nov	**5.33**	5.30	0.57	5.29	0.67	5.42	0.18	5.29	0.73
Dec	**4.41**	4.35	1.37	4.35	1.39	4.31	2.19	4.33	1.74
MPE		–	0.53	–	0.33	–	0.52	–	0.65
MBE		–	0.20	–	0.20	–	0.53	–	0.31
RMSE		–	0.89	–	0.47	–	1.05	–	0.96
t-test		–	2.37	–	1.37	–	2.64	–	2.57
NSE		–	0.9848	–	0.9994	–	0.9900	–	0.9818

Table10. Summary of maximum and minimum values of the statistical error tests, *MPE, MBE, RMSE, t-test,* and *NSE* of the fourteen models at the nine stations

Station	Value/ (Model Number)	*MPE*		*MBE*		*RMSE*		*t-test*		*NES*	
		Farthest from 0	**Closest to 0**	**Farthest from 0**	**Closest to 0**	**Farthest from 0**	**Closest to 0**	**Farthest from 0**	**Closest to 0**	**Farthest from 1**	**Closest to 1**
Sidi-Barrani	value	4.08	0.07	0.91	0.00	1.63	0.33	7.96	0.03	0.9502	0.9999
	(Model No.)	(6)	**(12)**	(5)	**(12)**	(4)	**(12)**	(11)	**(12)**	(5)	**(12)**
Matruh	value	5.12	0.11	2.78	-0.04	3.51	0.32	5.74	0.15	0.9588	0.9996
	(Model No.)	(2)	**(12)**	(2)	**(12)**	(4)	**(12)**	(2)	**(12)**	(4)	**(12)**
El-Arich	value	2.99	-0.08	2.27	0.13	3.43	0.22	5.78	0.19	0.9596	0.9997
	(Model No.)	(11)	**(12)**	(7)	**(12)**	(4)	**(12)**	(11)	**(12)**	(11)	**(12)**
Tahrir	value	2.56	-0.49	1.74	-0.39	3.08	0.53	4.87	0.32	0.9661	0.9993
	(Model No.)	(9)	**(12)**	(2)	**(12)**	(2)	**(12)**	(9)	**(12)**	(9)	**(12)**
Cairo	value	2.05	-0.04	1.66	0.01	2.27	0.33	3.63	0.86	0.9713	0.9999
	(Model No.)	(4)	**(12)**	(2)	**(12)**	(1)	**(12)**	(6)	**(12)**	(4)	**(12)**
El-Kharga	value	1.75	0.13	1.38	0.11	2.03	0.58	3.37	1.60	0.9727	0.9956
	(Model No.)	(1)	**(12)**	(1)	**(12)**	(1)	**(12)**	(4)	**(12)**	(4)	**(12)**
Qena	value	1.56	0.27	1.24	0.11	1.76	0.68	3.12	1.88	0.9734	0.9987
	(Model No.)	(1)	**(12)**	(1)	**(12)**	(1)	**(12)**	(1)	**(12)**	(1)	**(12)**
Aswan	value	0.98	0.12	0.90	0.12	1.47	0.47	2.84	1.37	0.9783	0.9994
	(Model No.)	(1)	**(12)**	(1)	**(12)**	(1)	**(12)**	(1)	**(12)**	(1)	**(12)**

5. Conclusions

The most accurate empirical models that estimate diffuse solar radiation were collected from the literature to evaluate their applicability for estimate diffuse solar radiation over Egypt. The collected models were compared on the basis of the many statistical error tests; relative percentage error *(e%),* mean percentage error (*MPE*), mean bias error (*MBD*), root mean square error (*RMSE*), *t-test,* and Nash-Sutcliffe equation (*NSE*). According to the results, the Tarhan and Sarı model (Model 12) showed the best estimation of the diffuse solar radiation on a horizontal surface for all stations. Therefore, the Tarhan and Sarı model (Model 12) is extremely recommended for predicting diffuse solar radiation at any location in Egypt.

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