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

S. M. Robaa

Astronomy, Space Sciences and Meteorology Department, Faculty of Science, Cairo University, Giza - Egypt
Email: d_robaa@hotmail.com

(Manuscript received in final form February 7, 2019)

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):

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

Model 2 (Ulgen and Hepbasli, 2009):

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

Model 3 (Gopinathan, 1988):

$$\frac{D}{H} = 0.697 - 0.577 \left(\frac{n}{N_0}\right),$$ (3)

Model 4 (Jamil and Akhtar, 2017):

$$\frac{D}{H} = 0.2932 - 1.8655 \left(\frac{H}{H_0}\right) - 1.5114 \left(\frac{n}{N_0}\right),$$ (4)
Model 5 (Gopinathan, 1988):
\[ \frac{D}{H} = 0.879 - 0.575 \left( \frac{H}{H_0} \right) - 0.323 \left( \frac{n}{N_o} \right), \] (5)

Model 6 (El-Sebaii et al. 2010):
\[ \frac{D}{H_0} = 3.0020 - 3.8820 \left( \frac{H}{H_0} \right) - 0.1500 \left( \frac{n}{N_o} \right), \] (6)

Model 7 (El-Sebaii and Trabea, 2003):
\[ \frac{D}{H} = -0.209 + 2.183 \left( \frac{n}{N_o} \right) - 1.785 \left( \frac{n}{N_o} \right)^2, \] (7)

Model 8 (Tarhan and Sarı, 2005):
\[ \frac{D}{H} = 0.9885 - 1.4276 \left( \frac{H}{H_0} \right) + 0.5679 \left( \frac{H}{H_0} \right)^2, \] (8)

Model 9 (Jamil and Akhtar, 2017):
\[ \frac{D}{H} = 0.3116 + 1.8043 \left( \frac{H}{H_0} \right) + 0.0501 \left( \frac{H}{H_0} \right)^2 - 1.5118 \left( \frac{n}{N_o} \right), \] (9)

Model 10 (Jamil and Akhtar, 2017):
\[ \frac{D}{H} = 0.3017 - 1.8726 \left( \frac{H}{H_0} \right) - 1.5454 \left( \frac{n}{N_o} \right) + 0.0212 \left( \frac{n}{N_o} \right)^2, \] (10)

Model 11 (Jamil and Akhtar, 2017):
\[ \frac{D}{H_0} = -0.1776 + 1.6206 \left( \frac{H}{H_0} \right) - 0.6843 \left( \frac{n}{N_o} \right) - 0.2136 \left( \frac{n}{N_o} \right)^2, \] (11)

Model 12 (Tarhan and Sarı, 2005):
\[ \frac{D}{H} = 1.0207 - 1.6582 \left( \frac{H}{H_0} \right) + 1.1018 \left( \frac{H}{H_0} \right)^2 - 0.4019 \left( \frac{H}{H_0} \right)^3, \] (12)

Model 13 (Aras et al. 2006):
\[ \frac{D}{H} = 1.7111 - 4.9062 \left( \frac{H}{H_0} \right) + 6.6711 \left( \frac{H}{H_0} \right)^2 - 3.9235 \left( \frac{H}{H_0} \right)^3, \] (13)

Model 14 (Jamil and Akhtar, 2017):
\[ \frac{D}{H} = 0.2191 + 2.3964 \left( \frac{H}{H_0} \right) - 0.3877 \left( \frac{H}{H_0} \right)^2 - 1.7828 \left( \frac{n}{N_o} \right) + 0.1705 \left( \frac{n}{N_o} \right)^2, \] (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):

$$H_o = \frac{24}{\pi} I_s f (\cos \varphi \cos \delta \sin w + \frac{2\pi}{360} w \sin \varphi \sin \delta),$$  \hspace{1cm} (15)$$

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

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

$$\delta = 23.45 \sin \left[\frac{360(284 + n')}{365}\right],$$  \hspace{1cm} (17)$$

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

$$N_o = 2w/15,$$  \hspace{1cm} (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 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* |
|-------------|--------------|---------------|---------------|-------------|----------------------------------|
| Sidi-Barrani| 31°38'       | 25°24'        | 27            | X X         | 1984                             |
| Matruh      | 31°20'       | 27°13'        | 38            | 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):

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

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

$$MBE = \frac{\sum_{i=1}^{N} (D_{i,m} - D_{i,c})}{N}, \quad (22)$$
\[
RMSE = \left( \frac{\sum_{i=1}^{N} (D_{i,m} - D_{i,c})}{N} \right)^{0.5}, \tag{23}
\]

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

\[
NSE = 1 - \frac{\sum_{i=1}^{N} (D_{i,m} - D_{i,c})^2}{\sum_{i=1}^{N} (D_{i,m} - D_{i,c})^2}, \tag{25}
\]

where \(D_{i,m}\) and \(D_{i,c}\) are the \(i\)th 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 \(\pm 10\%\) 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, $D_m$ (MJ.m$^{-2}$) and the corresponding calculated values, $D_c$ (MJ.m$^{-2}$), 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 | $D_m$ (1987–2016) | Model 1 |  | Model 2 |  | Model 3 |  | Model 4 |  | Model 5 |  | Model 6 |  | Model 7 |  | Model 8 |  | Model 9 |  | Model 10 |  |
|-------|------------------|---------|---|---------|---|---------|---|---------|---|---------|---|---------|---|---------|---|---------|---|---------|---|---------|---|
| 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  - 3.12  - 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 |
$RMSE$ - 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 |
| Month | Model 1 (1981-2016) | 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% | 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 |

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

- **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
| Month | Model 11 | Model 12 | Model 13 | Model 14 |
|-------|---------|---------|---------|---------|
|       | Dc     | e%     | Dc     | e%     | Dc     | e%     | Dc     | e%     |
| Jan   | 4.28   | 4.23   | 2.67   | 4.23   | 4.10   | 4.19   | 2.18   | 2.18   |
| Feb   | 5.91   | 5.96   | 5.95   | 5.96   | 5.95   | 5.96   | 5.95   | 5.96   |
| Mar   | 8.08   | 8.08   | 8.08   | 8.08   | 8.08   | 8.08   | 8.08   | 8.08   |
| Apr   | 9.33   | 9.33   | 9.33   | 9.33   | 9.33   | 9.33   | 9.33   | 9.33   |
| May   | 10.12  | 10.12  | 10.12  | 10.12  | 10.12  | 10.12  | 10.12  | 10.12  |
| Jun   | 9.43   | 9.43   | 9.43   | 9.43   | 9.43   | 9.43   | 9.43   | 9.43   |
| Jul   | 9.83   | 9.83   | 9.83   | 9.83   | 9.83   | 9.83   | 9.83   | 9.83   |
| Aug   | 8.72   | 8.72   | 8.72   | 8.72   | 8.72   | 8.72   | 8.72   | 8.72   |
| Sep   | 7.98   | 7.98   | 7.98   | 7.98   | 7.98   | 7.98   | 7.98   | 7.98   |
| Oct   | 6.48   | 6.48   | 6.48   | 6.48   | 6.48   | 6.48   | 6.48   | 6.48   |
| Nov   | 5.22   | 5.22   | 5.22   | 5.22   | 5.22   | 5.22   | 5.22   | 5.22   |
| Dec   | 4.46   | 4.46   | 4.46   | 4.46   | 4.46   | 4.46   | 4.46   | 4.46   |

**Table 3 continued**
### 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%     |
| 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   |
| Jan   | 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   |
| 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   |
| 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   |
| 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   |
| 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   |
| 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   |
| 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   |
| 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   |
| 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  |
| 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   |
| 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   |

|        | 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  |
| 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    |

\[
\begin{align*}
MPE &= -2.99 \\
MBE &= -1.11 \\
RMSE &= -1.88 \\
t-test &= -5.78 \\
NSE &= 0.9596
\end{align*}
\]
### Table 5. The same as Table 2, but for Tahrir

| Month | \(D_m\) (1987-2016) | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 | Model 9 | Model 10 |
|-------|---------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
|       | \(D_c\) | \(e\%) | \(D_c\) | \(e\%) | \(D_c\) | \(e\%) | \(D_c\) | \(e\%) | \(D_c\) | \(e\%) | \(D_c\) | \(e\%) | \(D_c\) | \(e\%) | \(D_c\) | \(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, -0.967, -0.9775, -0.9667, -0.998, -0.9661, -0.981
| 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
| Month | Dn (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 |
| 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 |

\[
\begin{align*}
MPE & = -0.77 & -0.04 & 0.16 & 0.74 \\
MBE & = -0.45 & 0.01 & 0.24 & 0.40 \\
RMSE & = -0.89 & 0.33 & 0.68 & 1.03 \\
t-test & = 2.80 & 0.86 & 1.92 & 2.99 \\
NSE & = -0.9774 & -0.9999 & -0.9927 & -0.9766
\end{align*}
\]
Table 7. The same as Table 2, but for El-Kharga

| Month | Dm (1987-2016) | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 | Model 9 | Model 10 |
|-------|----------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
|       |               | $Dc$ | $e\%$ | $Dc$ | $e\%$ | $Dc$ | $e\%$ | $Dc$ | $e\%$ | $Dc$ | $e\%$ | $Dc$ | $e\%$ | $Dc$ | $e\%$ | $Dc$ | $e\%$ | $Dc$ | $e\%$ |
| 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
- MBE
- RMS
- t-test
- NSE
Table 7. continued

| Month | $D_m$ (1987-2016) | Model 11 |   | Model 12 |   | Model 13 |   | Model 14 |   |
|-------|-------------------|----------|---|----------|---|----------|---|----------|---|
|       | $D_c$  | $e\%$   | $D_c$ | $e\%$   | $D_c$ | $e\%$   | $D_c$ | $e\%$   |
| 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    | 2.37 | 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 | 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%       |
| 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 | Dn (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, MBE: 0.73, RMSE: 0.71, t-test: 2.17, NSE: 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% |
| Jan   | 4.78 | 4.73 | 0.95 | 4.76 | 4.75 | 0.45 | 4.76 | 0.7 | 4.72 | 1.31 | 4.74 | 0.62 | 4.74 | 0.84 | 4.74 | 0.93 | 4.74 | 0.87 |
| Feb   | 5.64 | 5.67 | -0.62 | 5.66 | 5.65 | -0.32 | 5.67 | -0.14 | 5.61 | 0.61 | 5.61 | 0.55 | 5.60 | 0.75 | 5.60 | 0.78 | 5.60 | 0.70 |
| Mar   | 7.20 | 6.99 | 2.85 | 7.04 | 7.01 | 2.24 | 7.01 | 2.65 | 7.10 | 1.45 | 7.09 | 1.69 | 7.14 | 0.74 | 7.14 | 0.88 | 7.14 | 0.84 |
| Apr   | 7.96 | 7.65 | 3.92 | 7.70 | 7.66 | 3.26 | 7.71 | 3.13 | 7.70 | 3.24 | 7.73 | 2.86 | 7.73 | 2.95 | 7.73 | 2.90 | 7.74 | 2.82 |
| May   | 8.61 | 8.31 | 3.46 | 8.41 | 8.40 | 2.64 | 8.40 | 2.15 | 8.51 | 1.18 | 8.54 | 0.83 | 8.56 | 0.63 | 8.56 | 0.52 | 8.57 | 0.48 |
| Jun   | 8.90 | 8.54 | 4.08 | 8.59 | 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 |
| Jul   | 8.11 | 7.96 | 1.91 | 7.96 | 7.95 | 1.81 | 7.92 | 2.31 | 7.93 | 2.26 | 7.95 | 2.00 | 7.93 | 2.20 | 7.93 | 2.21 | 7.94 | 2.15 |
| Aug   | 8.12 | 7.92 | 2.43 | 7.92 | 7.90 | 2.44 | 7.92 | 2.17 | 7.89 | 2.84 | 7.88 | 2.95 | 7.89 | 2.80 | 7.89 | 2.88 | 7.89 | 2.83 |
| Sep   | 7.67 | 7.55 | 1.62 | 7.55 | 7.54 | 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 |
| Oct   | 6.21 | 6.36 | -2.48 | 6.33 | 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 |
| Nov   | 5.33 | 5.31 | 0.29 | 5.32 | 5.29 | 0.23 | 5.29 | 0.71 | 5.29 | 0.74 | 5.29 | 0.76 | 5.30 | 0.61 | 5.32 | 0.25 | 5.31 | 0.32 |
| Dec   | 4.41 | 4.32 | 1.99 | 4.29 | 4.26 | 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 |

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

Table 16. 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.
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 Sari model (Model 12) showed the best estimation of the diffuse solar radiation on a horizontal surface for all stations. Therefore, the Tarhan and Sari model (Model 12) is extremely recommended for predicting diffuse solar radiation at any location in Egypt.

References

Al-Mohamad A., 2004: Global, direct and diffuse solar radiation in Syria. Appl Energy 79 (2), 191–200. https://doi.org/10.1016/j.apenergy.2003.12.011
Almorox, J., and Hontoria C., 2004: Global solar radiation estimation using sunshine duration in Spain. Energy Conv. Manage 45, 1529–35. https://doi.org/10.1016/j.enconman.2003.08.022
Aras, H., Balli, O., Hepbasli, A., 2006: Estimating the horizontal diffuse solar radiation over the Central Anatolia region of Turkey. Energy Conv. Manage 47, 2240–2249. https://doi.org/10.1016/j.enconman.2005.11.024
Chen, R., Ersi, K., Yang, J., Lu, S., Zhao, W., 2004: Validation of five global radiation models with measured daily data in China. Energy Conv. Manage 45, 1759–69. https://doi.org/10.1016/j.enconman.2003.09.019
Darwish, M. A., and Taha, N. E., 2000: Estimation of diffuse radiation over the Arab World (Eastern Region). 5th conference-Meteorology & Sustainable development 22–24 February 2000. Cairo, Egypt.
Driesse, A. and Thevenard, D. A., 2002: Test of Suehrcke’s sunshine radiation relationship using a global data set. Sol. Energy 72, 167–75. https://doi.org/10.1016/S0038-092X(01)00082-2
Duffie, J. A. and Beckman, W. A., 1991: Solar engineering of thermal process. New York: Wiley.
El-Metwally, M., 2004: Simple new methods to estimate global solar radiation based on meteorological data in Egypt. Atmos. Res. 69, 217–239. https://doi.org/10.1016/j.atmosres.2003.09.002
El-Metwally, M., 2005: Sunshine and global solar radiation estimation at different sites in Egypt. J. Atmos. Solar –Terr. Phys. 67, 1331–1342. https://doi.org/10.1016/j.jastp.2005.04.004
El-Metwally, M. and Wald, L., 2013: Monthly means of daily solar irradiation over Egypt estimated from satellite database and various empirical formulae. Int. J. Remote Sens. 34, 8182–8198. https://doi.org/10.1080/01431161.2013.834393
El-Sebaii, A.A., and Trabea, A.A., 2003: Estimation of horizontal diffuse solar radiation in Egypt. Energy Conv. Manage. 44, 2471–2482. https://doi.org/10.1016/S0196-8904(03)00004-9
El-Sebaii, A.A., and Trabea, A.A., 2005: Estimation of Global Solar Radiation on Horizontal Surfaces over Egypt. Egypt. J. Solids. 28, 163–175.
El-Sebaii, A.A., Al-Hazmi, F. S., Al-Ghamdi, A.A., Yaghmour, S.J., 2010: Global, direct and diffuse solar radiation on horizontal and tilted surfaces in Jeddah, Saudi Arabia. Appl. Energy 87, 568–76. https://doi.org/10.1016/j.apenergy.2009.06.032
El-Shahawy, M.A., 1984: Estimation of daily global solar radiation. Bull. Fac. Sci. Cairo Univ. 52, 641–653.
El-Shazly, M.S., Abdelmageed, A.M. and El-Noubi, M., 1998: Solar radiation characteristics at Qena/ Egypt. Mausam 49, 59–70.
Gopinathan, K.K., 1988: Empirical correlations for diffuse solar radiation. Sol Energy 40, 369–70. https://doi.org/10.1016/0038-092X(88)90009-6
Hawas, M.M. and Muneer, T., 1984: Study of diffuse and global radiation characteristic in India. Energy Conv. Manage 24, 143–9. https://doi.org/10.1016/0196-8904(84)90026-8
Ibrahim, S.M.A., 1985: Predicted and measured solar radiation in Egypt. *Sol Energy* 35, 185–8. https://doi.org/10.1016/0038-092X(85)90009-X

Jamil, B. and Akhtar, N., 2017: Comparative analysis of diffuse solar radiation models based on sky clearness index and sunshine period for humid-subtropical climatic region of India: A case study. *Renew. Sustain. Energy Rev.* 78, 329–355. https://doi.org/10.1016/j.rser.2017.04.073

Khalil, S.A., and Shaffie, A. M., 2013: A comparative study of total, direct and diffuse solar irradiance by using different models on horizontal and inclined surfaces for Cairo, Egypt. *Renew. Sustain. Energy Rev.* 27, 853–63. https://doi.org/10.1016/j.rser.2013.06.038

Khalil, S.A., and Shaffie, A.M., 2016: Evaluation of transposition models of solar irradiance over Egypt. *Renew. Sustain. Energy Rev.* 66, 105–119. https://doi.org/10.1016/j.rser.2016.06.066

Kumar, R. and Umanand, L., 2005: Estimation of global radiation using clearness index model for sizing photovoltaic system. *Renew Energy* 30, 2221–2233. https://doi.org/10.1016/j.renene.2005.02.009

Li, D.H.W. and Lam, J.C., 2000: Solar heat gain factors and the implications for building designs in subtropical regions. *Energy Build.* 32, 47–55. https://doi.org/10.1016/S0378-7788(99)00035-3

Lu, Z., Piedrahita R.H., and Neto, C.D.S., 1998: Generation of daily and hourly solar radiation values for modeling water quality in aquaculture ponds. *Trans ASAE* 41, 1853–1859. https://doi.org/10.13031/2013.17323

Mediavilla, M.D., Miguel, A., and Bilbao, J., 2005: Measurement and comparison of diffuse solar irradiance models on inclined surfaces in Valladolid, Spain. *Energy Conv. Manage* 46, 2075–92. https://doi.org/10.1016/j.enconman.2004.10.023

Norton, G., Cristofari, C., and Muselli, M., Poggi, P., 2004: Calculation on an hourly basis of solar diffuse irradiations from global data for horizontal surfaces in Ajaccio. *Energy Conv. Manage* 45, 2849–2866. https://doi.org/10.1016/j.enconman.2004.01.003

Sabbagh, J.A., Sayigh, A.M., El Salam, E.M., 1977: Estimation of the total radiation from meteorological data. *Solar Energy* 19, 307–311. https://doi.org/10.1016/0038-092X(77)90075-5

Soares, J., Oliveira, A. P., Bozinar, M. Z., Mlakar, P., Escobedo, J. F., and Machado, A.J., 2004: Modeling hourly diffuse solar radiation in the city of Sao Paulo using a neural network technique. *Appl. Energy* 79, 201–214. https://doi.org/10.1016/j.apenergy.2003.11.004

Stone, R.J., 1993: Improved statistical procedure for the evaluation of solar radiation models. *Sol Energy* 51, 289–91. https://doi.org/10.1016/0038-092X(93)90124-7

Tadros, M.T.Y., 2000: Uses of Sunshine Duration to Estimate the Global Solar Radiation over Eight Meteorological Stations in Egypt. *Renew. Energy* 21, 231–246. https://doi.org/10.1016/S0960-1411(00)00009-4

Tarhan, S., and Sari, A., 2005: Model selection for global and diffuse radiation over the Central Black Sea (CBS) region of Turkey. *Energy Conv. Manage* 46, 605–613. https://doi.org/10.1016/j.enconman.2004.04.004

Tiba, C., 2001: Solar radiation in the Brazilian Northeast. *Renew. Energy* 22, 565–578. https://doi.org/10.1016/S0960-1411(01)00116-6

Togrul, I.T., and Togrul, H., 2002: Global solar radiation over Turkey: comparison of predicted and measured data. *Renew. Energy* 25, 55–67. https://doi.org/10.1016/S0960-1411(00)00197-X

Trabea, A., and Shaltout, M.A., 2000: Correlation of Global Solar Radiation with Meteorological Parameters over Egypt. *Renew. Energy* 21, 297–308. https://doi.org/10.1016/S0960-1411(99)00127-5

Tymvios, F.S., Jacovides, C.P., Michaelides, S.C., and Scouteli, C., 2005: Comparative study of Angstrom and artificial neural networks methodologies in estimating global solar radiation. *Sol Energy* 78, 752–62. https://doi.org/10.1016/j.solener.2004.09.007

Ulgen, K., and Hepbasli, A., 2002: Comparison of solar radiation correlations for Izmir, Turkey. *Int. J. Energy Res.* 26, 413–430. https://doi.org/10.1002/er.794

Ulgen, K., and Hepbasli, A., 2003: Comparison of diffuse fraction of daily and monthly global radiation for Izmir, Turkey. *Energy Sour.* 25, 637–649. https://doi.org/10.1080/00908310390212444

Ulgen, K., and Hepbasli, A., 2004: Solar radiation models. Part 2: Comparison and developing new models. *Energy Sour.* 26, 521–530. https://doi.org/10.1080/00908310490429704

Ulgen, K., and Hepbasli, A., 2009: Diffuse solar radiation estimation models for Turkey's big cities. *Energy Conv. Manage* 50, 149–56. https://doi.org/10.1016/j.enconman.2008.08.013

Wong, L.T., and Chow, W.K., 2001: Solar radiation model. *Appl. Energy* 69, 191–224. https://doi.org/10.1016/S0306-2619(01)00012-5