A Comparison Assessment of Measuring Evapotranspiration in Egypt

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ABSTRACT

Scarcе water resources management makes accurate measurements of different parameters of water requirements very critical. Therefore, the values for crop evapotranspiration and crop water requirement are identical. Crop water requirements refer to the amount of water that is needed to be supplied efficiently. Therefore, there are many models and tools which were used in this study are used in this study as a practical tool to calculate actual evapotranspiration such as the CROPWAT model. Moreover, Eddy Covariance and ET-Watch model are methods used to estimate evapotranspiration. The main goal of the study was to assess daily and decadal actual evapotranspiration using Eddy covariance and ET-Watch model under arid land conditions then compare results with CROPWAT model result. Egypt was used as an example. Results showed that Eddy covariance ETA values for both crops were lower than ETA values from CROPWAT, while ET-Watch values were somewhat close to CROPWAT values. For cotton, the intercept of the linear relationship for daily ETA were 1.73 and 2.15, respectively between Eddy covariance and CROPWAT. For decadal ETA were 1.101 and 0.69. Its highly recommended to use ETWatch when predicting daily ETA, while for decadal ETA both Eddy covariance and ETWatch could be used with no big differences.

Keywords: Evapotranspiration, Eddy Covariance, CROPWAT, ET-Watch Egypt

INTRODUCTION

Evapotranspiration (ET) is a collective term used to characterize water removal from earth’s surface into the atmosphere by the combination of evaporation and transpiration mechanisms Liou and Kar (2014). These two mechanisms occur simultaneously and the distinction between the two phases cannot be rendered easily Allen et al. (1998). The FAO Penman–Monteith (FAO-PM) method is suggested as the main reference evapotranspiration (ETo) method based on meteorological data Allen et al. (1998); Todorovic et al. (2013). In many regions and climates the FAO method was shown to be capable of providing consistent ET0 values and it was long accepted worldwide as a good ET0 estimator compared to other approaches, particularly in daily calculations Temesgen et al. (2005); Xing et al. (2008). The evapotranspiration can be calculated either directly with weighting lysimeters or with a technique of eddy correlation or indirectly with the use of surface energy balance Farahani et al. (2007). Ragab et al. (2017) reported that the actual crop water requirement based on modern technologies could save at least 50% of irrigation water. Another benefit is that these modern technologies do not need the crop coefficient Kc, which for many irrigation practitioners is difficult to obtain. Eddy Covariance (EC) method have been commonly used since the 1990s to measure the biosphere exchange of energy, gases and water vapor Hassan and Bourque (2006). Burba (2013) said that Eddy Covariance is one of the most precise and defensible methods to calculating emission of different gases and water vapor over scales ranging from few hundreds to millions of square meters. Eddy covariance is useful to quantify fluxes since the technique provides direct measuring over a canopy ranging from a few meters to several hundred meters, and calculations on a time scale from hours to years can be made Baldocchi (2014).

Classic methods for the measurement of evapotranspiration (ET) such as Eddy covariance are possible in the field scale, but do not qualify for estimated when interacting with large scales Courault et al. (2005).

Remote sensors easily acquire the broad spectrum of regional and global targets knowledge to enable data modeling and recovery of different ecological indicators. Therefore remote sensing has become an essential ecological monitoring approach, especially at a wide or global level Li et al. (2020). Courault et al. (2005) specify four types of remote sensing models based on empirical direct methods, residual methods of the energy budget, deterministic methods and vegetation index methods. Liou and Kar (2014) outlined various ET models (algorithms) for remote sensing based on Surface Energy Balance approach and mentioned out its input parameters, main assumptions, merits and demerits, these models were Surface Energy Balance Index (SEBI), Surface Energy Balance System (SEBS), Simplified Surface Energy Balance Index (SSEBI), Surface Energy Balance Algorithm for Land (SEBAL), Mapping Evapotranspiration at High Resolution and with Internalized Calibration (METRIC) and Two-Source Models (TSM). Wu et al. (2008) created remote sensing ETWatch detection system which is a chain that begins from pre-processing data to applications items, using spatial information on climatic data, soil type, land usage,
cover of vegetation, digital elevation, and remotely sensing factors for the land surface. ETWatch is an integration of the “Residue Approach” and Penman Monteith (P–M). The energy balance model, is computed from spectral radiances in the cloudless atmosphere. For the first time outside China, the ETWatch model was developed in Egypt in 2017 by El-Shirbeny et al. (2018). To optimize water productivity, the main goal of the study is to find out the best methodology that can be applied for accurate measurement of evapotranspiration. Then comparing ET predictions from these methods with ET calculated from CROPWAT. Eddy covariance (EC) and the MODIS ET product using ETWatch model was verified at Zankalon site at Sharkia, Egypt.

MATERIALS AND METHODS

Study area

The study area was allocated in Zankalon Water Requirements Experimental Station. It is in the eastern part of the Nile Delta, Sharkia Governorate, Egypt. The site is located at 30° 35’ N and 31° 30’ E with an elevation of about 7 meters above sea level. Cotton was selected (summer crop from 1 May 2014 to 16 October 2014) and wheat (winter crop from 1 December 2014 to 10 May 2015).

Climate data used in this study were based on mainly daily meteorological data including Maximum and Minimum Temperature, Humidity, and Wind speed for years 2014 and 2015 from the automatic weather station in Zankalon weather station, Sharkia Governorate, Egypt. Sunshine hour and rainfall data from (Worldweatheronline) web site.

The soil type in the study area belongs to heavy clay class according to Atta (2007), table (1) describe some soil physical and chemical properties.

<p>| Table 1. Some soil physical and chemical properties of the study area, Atta (2007) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th><strong>Depth (cm)</strong></th>
<th><strong>Sand (%)</strong></th>
<th><strong>Silt (%)</strong></th>
<th><strong>Clay (%)</strong></th>
<th><strong>Remainder (%)</strong></th>
<th><strong>Texture</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>25.80</td>
<td>28.90</td>
<td>43.51</td>
<td>1.79</td>
<td>clay</td>
</tr>
<tr>
<td>15-30</td>
<td>25.12</td>
<td>30.10</td>
<td>42.80</td>
<td>2.28</td>
<td>clay</td>
</tr>
<tr>
<td>30-45</td>
<td>26.90</td>
<td>31.50</td>
<td>40.50</td>
<td>1.10</td>
<td>clay</td>
</tr>
<tr>
<td>45-60</td>
<td>29.78</td>
<td>31.50</td>
<td>37.12</td>
<td>1.60</td>
<td>clay</td>
</tr>
<tr>
<td>Average</td>
<td>26.90</td>
<td>30.50</td>
<td>40.91</td>
<td>1.69</td>
<td>clay</td>
</tr>
</tbody>
</table>

Tested methods

The chosen methods for this study were CROPWAT using (Penman–Monteith equation), Eddy covariance method, and ETWatch model as follow:

CROPWAT model with (P–M) equation

Smith (1992) developed FAO-CROPWAT 8.0 which is a Computer Program for Irrigation Planning and Management. It can calculate Reference evapotranspiration, Crop water requirements, and Crop irrigation requirements. It allows to improving irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of crop production under rain deficit or deficit irrigation.

\[
\text{ETo} = \frac{0.408(\frac{Rn-G}{\Delta T}) + 900}{\Delta + \gamma(1 + 0.34\Delta u_2)}
\]

Where:

- \(\text{ETo}\) = reference evapotranspiration (mm day\(^{-1}\))
- \(Rn\) = net radiation at the crop surface (MJ m\(^{-2}\) day\(^{-1}\))
- \(G\) = soil heat flux density (MJ m\(^{-2}\) day\(^{-1}\))
- \(T\) = mean daily air temperature at 2 m height (°C)
- \(u_2\) = wind speed at 2 m height (m s\(^{-1}\))
- \(e_s\) = saturation vapour pressure (kPa)
- \(e_a\) = actual vapour pressure (kPa)
- \(\Delta\) = slope vapour pressure curve (kPa °C\(^{-1}\))
- \(\gamma\) = psychrometric constant (kPa °C\(^{-1}\))

Eddy covariance

Eddy Covariance (EC) method is a direct micrometeorological flux measurement, which provides exchange energy fluxes at high temporal resolution (typically 30-min interval). EC system consisted of a three-dimensional sonic anemometer (SAT) used to measure wind speed in three dimensions 10 times per second and virtual temperature, hygrometer measures vapor pressure at a frequency of 10 Hz, and soil heat flux plate. EC data included daily data Net radiation (Rn), Sensible heat flux (H), Soil heat flux (G) and Latent heat flux (\(\lambda ET\)) for 2014 and 2015 years from Zankalon tower station with an elevation of about 15 meters. According to Cleverly et al. (2002) ETa from eddy covariance (EC) is calculated from the latent heat flux as:

\[
\text{ETa} = \frac{L}{\lambda} \frac{\text{LE}}{w}
\]

Where:

- \(\text{ETa}\) = actual evapotranspiration (mm/day), \(L\) = Latent heat flux (W/m\(^2\)), \(\lambda\) = latent heat of vaporization of water (2441kJ/kg), \(w\) = density of water (kg/m\(^3\)).

ETWatch-Egypt model

ETWatch model was developed by the ETWatch team at the Digital Agriculture, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences. It has been installed and operated in National Authority for Remote Sensing & Space Sciences in Egypt (NARSS). It is an evapotranspiration (ET) monitoring system based on remote sensing and sub models developed by the ETWatch team of RADI: net radiation, soil heat flux, sensible heat flux, latent heat flux, gap filling and ET data fusions. It is the first operational platform in the world with well-managed data and extensibility, guarantying the series ET data production. ET is an important parameter for water management and irrigation management departments Wu et al. (2012); Wu et al. (2016); Wu et al. (2017).

ETWatch model description shown in Figure (1). It establishes an ET processing system based on remote sensing technologies and ETWatch model, forms a service flow from remote sensing data preprocessing to evapotranspiration (ET) estimation, and provides an ET monitoring platform, serving for water consumption management in Egypt. Principles of evapotranspiration
Estimation in ETWatch are according to the surface energy balance as the following equation;

\[ R_n = \lambda E + H + G \]

Where:
- \( R_n \) = net (all-wave) radiant energy (W/m²),
- \( \lambda E \) = latent heat flux (W/m²),
- \( H \) = sensible heat flux (W/m²),
- \( G \) = soil heat flux (W/m²).

ETWatch model required many input data; 1) Base data: DEM (digital elevation model), slope, aspect, land cover; 2) RS data: MODIS, FY-2D (Fengyun-2D geostationary meteorological satellite), ARIS (The Atmospheric Infrared Sounder), LANDSAT, MSG (Meteosat Second Generation geostationary meteorological satellite; and 3) Meteorological data: daily data (air pressure, humidity, minimum and maximum temperature, wind speed). All data needed as (TIF) image format file were included with the support of the National Authority for Remote Sensing & Space Sciences (NARSS).

**RESULTS AND DISCUSSION**

Eddy covariance ETa values were always lower than ETa values from FAO-PM (CROPWAT model), these results agree with Ragab et al. (2017) results. In ETWatch model ETa values were slightly higher. ETWatch model isn’t an open-source model. It considered complicated and need high experience and time to prepare input data.

**ETa comparisons and statistical analysis**

FAO CROPWAT model contains procedures of crop water requirements and for irrigation scheduling FAO (2009). It allows the simulation of crop water use under various climate, crop and soil conditions. It is widely used for defining crops water requirements all over the world Surendran et al. (2015) because of its simplicity, easiness to use and being linked to less intense data requirements. This model was used for comparison as eddy covariance technique is not widely available in Egypt. It is an expensive method. The measurements are sometimes difficult to explain when atmospheric turbulence is weak, which occurs commonly at night and data may require gap-filling techniques Aubinet (2008); Novick et al. (2009).

The comparison between methods of evaluating ETa (such as Eddy covariance and ETWatch model) against CROPWAT model at daily and decadal (approximately every 10 days) basis was determined using statistical tools. The slope, intercept, coefficient of determination (R²), root mean square error (RMSE) and mean bias error (MBE) were considered in the comparison.

The correlation results between the tested methods for cotton daily ETa are indicated in Figure (2). This figure indicated the linear regression analysis for Eddy covariance, ETWatch model to test the accuracy of its results by the range of their closeness to the “best fit” line (1:1). The slopes of Eddy covariance and ETWatch model were 0.26 and .33, respectively. While, for decadal ETa as shown in figure (3) of Eddy covariance and ETWatch model were 0.24 and 0.33, respectively.

From the results, it was observed that ETWatch model had is more reliable than Eddy covariance. The intercept of the linear relationship between values of daily ETa obtained from Eddy covariance and CROPWAT was 1.737. While the corresponding values was 2.15 between ETWatch model and CROPWAT. When replacing daily ETa results with decadal ETa results, the values of intercept of 1.91 and 2.039 were recorded, respectively.

Table (2) indicates a highly significant differences at 1% level between values of daily ETa among the three prediction methods. Calculated F value was 93.847. Table
(3) indicates some descriptive statistics for the values of daily ETa obtained from different methods. For decadal ETa results, a highly significant was found between different methods at 1% level of significance. The F value was 9.651 as in table (4). Some descriptive statistics for decadal ETa are also summarized in table (5). A comparative study was made between Eddy covariance and ETWatch model with respect to both daily and decadal ETa values as shown in table (6). As indicated in the previous table, ETWatch model is more accurate than Eddy covariance method because the first method is accompanied by higher $R^2$ values with CROPWAT model. The previous conclusion is quite obvious with the results of daily ETa. The arrangement of performance as measured through RMSE was ETWatch model then Eddy covariance for (daily - decadal) ETa; and the arrangement of performance as measured through MBE was the same for (daily - decadal) ETa.

![Figure 2. Scatter plot of daily ETa values among CROPWAT model and tested methods for cotton](image1)

![Figure 3. Scatter plot of decadal ETa values among CROPWAT model and tested methods for cotton](image2)

Table 2. Analysis of variance for relationship among the tested methods on daily ETa values for cotton

<table>
<thead>
<tr>
<th>S. V</th>
<th>S.S.</th>
<th>DF</th>
<th>M.S.</th>
<th>F value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treat</td>
<td>434.569</td>
<td>2</td>
<td>217.284</td>
<td>93.847</td>
<td>**</td>
</tr>
<tr>
<td>Error</td>
<td>1166.912</td>
<td>504</td>
<td>2.315</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1601.481</td>
<td>506</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Highly significant at 1% level
S.V is source of variation, S.S. is sum of squares, DF is degrees of freedom and M.S. is mean squares

Table 3. Means, Std. Deviation and Std. Error from the analysis of variance in the tested methods on daily ETa values for cotton

<table>
<thead>
<tr>
<th>Calculation method</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>CROPWAT</td>
<td>5.527</td>
<td>2.2810</td>
<td>0.1755</td>
</tr>
<tr>
<td>Eddy covariance</td>
<td>3.323</td>
<td>0.8154</td>
<td>0.0627</td>
</tr>
<tr>
<td>ETWatch</td>
<td>3.965</td>
<td>1.0383</td>
<td>0.0799</td>
</tr>
<tr>
<td>$F = (93.847)$</td>
<td>$P &lt; 0.01$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Scatter plot of daily ETa values among CROPWAT model and tested methods for winter crop (wheat)

The slopes for wheat daily ETa as shown in Figure (4) for Eddy covariance and ETWatch model were 0.20 and 0.51, respectively. While, for decadal ETa Eddy covariance, ETWatch model as shown in figure (5) were 0.21 and 0.53, respectively. It shows that ETWatch model had high prediction than Eddy covariance. The intercept of the linear relationship for daily ETa were 1.09 and 0.663, respectively between Eddy covariance and CROPWAT, ETWatch model and CROPWAT. While, for decadal ETa were 1.101 and 0.69.
The calculated F value = 88.366 in table (7) was highly significant at 1% level and descriptive statistics are described in table (8) for daily ETa values. For decadal ETa F value = 7.786 in table (9) was highly significant at 1% level and descriptive statistics described in table (10). As shown in table (11) the arrangement of performance as measured through RMSE was ETWatch model then Eddy covariance for (daily - decadal) ETa; and the arrangement of performance as measured through MBE was ETWatch model then Eddy covariance for (daily - decadal) ETa. ETWatch model is accompanied by higher $R^2$ values with CROPWAT model than Eddy covariance, this is quite obvious with the results of daily ETa.

Table 7. Analysis of variance for relationship among the tested methods on daily ETa values for wheat

<table>
<thead>
<tr>
<th>S. V</th>
<th>S.S.</th>
<th>DF</th>
<th>M.S.</th>
<th>F value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treat</td>
<td>142.722</td>
<td>2</td>
<td>71.361</td>
<td>88.366</td>
<td>**</td>
</tr>
<tr>
<td>Error</td>
<td>387.629</td>
<td>480</td>
<td>0.808</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>530.351</td>
<td>482</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Highly significant at 1% level
S.V is source of variation, S.S. is sum of squares, DF is degrees of freedom and M.S. is mean squares

Table 8. Means, Std. Deviation and Std. Error from the analysis of variance in the tested methods on daily ETa values for wheat

<table>
<thead>
<tr>
<th>Calculation method</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>CROPWAT</td>
<td>3.025</td>
<td>1.2907</td>
<td>0.1017</td>
</tr>
<tr>
<td>Eddy covariance</td>
<td>1.705</td>
<td>0.3517</td>
<td>0.0277</td>
</tr>
<tr>
<td>ETWatch</td>
<td>2.210</td>
<td>0.7957</td>
<td>0.0627</td>
</tr>
<tr>
<td>F = (88.366)</td>
<td></td>
<td></td>
<td>P &lt; 0.01</td>
</tr>
</tbody>
</table>

Table 9. Analysis of variance for relationship among the tested methods on decadal ETa values for wheat

<table>
<thead>
<tr>
<th>S. V</th>
<th>S.S.</th>
<th>DF</th>
<th>M.S.</th>
<th>F value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treat</td>
<td>10.908</td>
<td>2</td>
<td>5.454</td>
<td>7.786</td>
<td>**</td>
</tr>
<tr>
<td>Error</td>
<td>31.520</td>
<td>45</td>
<td>0.700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>42.427</td>
<td>47</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Highly significant at 1% level
S.V is source of variation, S.S. is sum of squares, DF is degrees of freedom and M.S. is mean squares

Table 10. Means, Std. Deviation and Std. Error from the analysis of variance in the tested methods on decadal ETa values for wheat

<table>
<thead>
<tr>
<th>Calculation method</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>CROPWAT</td>
<td>2.864</td>
<td>1.2283</td>
<td>0.3071</td>
</tr>
<tr>
<td>Eddy covariance</td>
<td>1.700</td>
<td>0.2852</td>
<td>0.0713</td>
</tr>
<tr>
<td>ETWatch</td>
<td>2.206</td>
<td>0.7150</td>
<td>0.1788</td>
</tr>
<tr>
<td>F = (7.786)</td>
<td></td>
<td></td>
<td>P &lt; 0.01</td>
</tr>
</tbody>
</table>

Table 11. Statistical performance of EC and ETWatch model for estimating (daily- decadal) ETa for wheat

<table>
<thead>
<tr>
<th>ETa</th>
<th>$R^2$</th>
<th>RMSE (mm/day)</th>
<th>MBE (mm/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily</td>
<td>0.56</td>
<td>0.69</td>
<td>1.69</td>
</tr>
<tr>
<td>Decadal</td>
<td>0.81</td>
<td>0.83</td>
<td>1.50</td>
</tr>
</tbody>
</table>

$R^2$ the correlation coefficient, RMSE is the root mean square error and MBE the mean bias error

CONCLUSION

The study is focused on measuring and comparing actual evapotranspiration from two methods Eddy covariance and ETWatch-Egypt model and comparing with CROPWAT model. ETa daily values obtained from EC method was compared with CROPWAT model, the coefficient of determination ($R^2$) for summer season
(cotton) and for winter season (wheat) were equal 0.64 and 0.56, respectively. The calculated R² values were reliable as it close to results of Er-Raki et al. (2009); Ha et al. (2015); Reavis (2017); Ochoa-Sánchez et al. (2019). Examining the results of decadal ETa, one can observe that the values of regression of determination (R²) are becoming higher than daily ETa, also the values of R² are becoming closer for the two methods for two seasons.

**RECOMMENDATIONS**

Eventually, it is recommended to use CROPWAT model if only meteorological data are available for calculating crop water requirements. This is due to its availability and simplicity to use. It also allows the simulation of crop water use under various climate, crop, and soil conditions.

The Eddy covariance is approved to be a powerful method to estimate the surface-atmosphere exchange at the ecosystem scale especially evapotranspiration especially with the decadal ETa results. Unfortunately, it is not widely available in Egypt, it is an expensive method, and the measurements are sometimes difficult to explain when atmospheric turbulence is weak, this occurs mostly at night. In general, it gives lower ETa results than measured with FAO (P-M) equation.

Its highly recommended to use ETWatch when predicting daily ETa, while in predicting decadal ETa both Eddy covariance and ETWatch could be used with no big differences. Due to importance of calculation of actual ET especially where there is shortage of freshwater resources, it is strongly recommended to find an accurate and applicable methodology for the direct measurement of actual ET.

**REFERENCES**


