Article

Accuracy Testing of ETo Calculator (Ukraine) App: A Comparison Between Penman-Monteith and Temperature-Based Reference Evapotranspiration Assessment Methods

Pavlo Lykhovyd [1]

[1] The Institute of Irrigated Agriculture of NAAS; pavel.likhovid@gmaill.com
* Correspondence pavel.likhovid@gmail.com; Tel.: +380660629897

Abstract: Reference evapotranspiration (ETo) is a key agrometeorological index for rational irrigation management. The standard method for ETo estimation, proposed by FAO, is based on a complicated Penman-Monteith equation, requires great number of meteorological inputs thus making it difficult for practical use by farmers. To the moment, there are many alternative simplified approaches for ETo estimation, most of them are directed to cutting the number of required meteorological inputs for calculation. Among them, special attention should be paid to various temperature-based methods of ETo assessment. One of the temperature-based models for ETo computation was realized in free mobile app ETo Calculator (Ukraine). The app gives Ukrainian farmers an opportunity to assess ETo values on daily or monthly scale using mean air temperature as the only input. The goal of the study was to test the app accuracy comparing to FAO-based calculations in five key regions of Ukraine, each of which representing a particular climatic zone of the country. It was established that the app provides relatively good accuracy of ETo estimation even in raw (not adjusted to windspeed and relative air humidity) run; the results of statistical comparison with the FAO-calculated values are: R^2 within 0.82-0.87, RMSE within 0.74-0.81 mm, MAE within 0.60-0.70, MAPE within 18.07-25.50% depending on the region. ETo Calculator (Ukraine) is a good alternative for complicated Penman-Monteith method and could be recommended for Ukrainian farmers to be used for irrigation management.

Keywords: agrometeorology; irrigation; information technology; statistics; water management

1. Introduction

Rational use of water resources in agriculture is crucial for ecological sustainability. Current scientific evidence supports the idea of increasing global freshwater scarcity under simultaneous deterioration of water quality. Agriculture is one of the most demanding branches of global economy, and the demand for freshwater is expected to be increased in the nearest future due to the aggravation of global warming, especially in vulnerable areas of Africa, Middle East, and Southern Asia [1]. Therefore, the problem of rational and at most economical use of water in agricultural sector, especially in irrigated crop production, is on the table for modern society.

Rational irrigation water management is impossible without scientifically based approach to the determination of water demands for crop production. The basis for this is calculation of reference evapotranspiration – an index, which represents the losses of water per certain time span from a certain land plot. Reference evapotranspiration (or ETo) is a basic parameter for further estimation of irrigation requirements for a particular crop. Therefore, accurate and operational estimation of ETo is crucial for irrigation demands establishment and irrigation scheduling [2].

To the moment, dozens of different approaches for ETo estimation have been developed. The best way is direct field measurement using a lysimeter. But this method is expensive, laborious, and unsuitable for production conditions. Considering the mentioned

 doi:10.20944/preprints202206.0337.v1

drawbacks, indirect methods for reference evapotranspiration derivation from meteorological data were developed [3–5]. Each computation approach has its unique algorithm and advantages, but finally FAO and scientific society approved as the standard the method known as Penman-Monteith equation [6]. This methodology was put in the basis for most software used to determine irrigation demands, both FAO-delivered (as CROPWAT, AquaCrop, etc.) or provided by exterior developers. The main weakness of this method is its high complexity and demand for huge number of meteorological inputs, which are often inaccessible for ordinary farmer. Besides, there is a lack of free mobile apps for ETo estimation using Penman-Monteith equation that makes it unsuitable for use in the field conditions. Hence the necessity for simplification of reference evapotranspiration calculation model arose, and most developers struggle to cut the number of required meteorological inputs without loss of estimation accuracy [7–8]. On another hand, fully automated computation mobile systems were developed, e.g., EVAPO and AgSAT mobile apps, requiring just pointing out the coordinates of irrigation plot on the global map and waiting for automatic estimation of ETo by the external data from NASA servers [9]. Such an approach is quite comfortable for user, but the studies found that it is not reliable enough [10–11].

Further, another approach for ETo assessment on the local level was proposed: temperature-based regression models. For example, such models were developed for every region of Ukraine, and then aggregated in the mobile app – ETo Calculator (Ukraine) [12–13]. The approach is promising; however, it remains unclear whether the developed models are reliable and accurate in reference evapotranspiration estimation using meteorological data that do not fall within the period of 1971-2020 (the period used to create models for ETo assessment). The goal of this study was to check out performance of ETo Calculator (Ukraine) mobile app in estimation of reference evapotranspiration in 2021 by the key regions of the country in comparison to the estimation using FAO-based calculations of Penman-Monteith equation.

2. Materials and Methods

Assessment of ETo Calculator (Ukraine) accuracy was performed through direct comparison of its calculations with those performed in a FAO-based add-in for MS Excel. The mobile app is available for downloading and installation on Android smartphones by the link https://play.google.com/store/apps/details?id=com.EvapUkr. The calculations by Penman-Monteith were held using an adapted ETo assessment tool for MS Excel developed by Sherzod Rusmetov (guidelines and download link are available for free at https://youtu.be/1xT1CmDe2gc), and engaged such inputs as site elevation, latitude, minimum and maximum air temperature, windspeed, sunlight hours, etc. Meteorological data were taken from the observations of regional hydrometeorological centers (available at http://pogodaiklimat.ru) and meteorological reference book [14–15]. Calculations results obtained within ETo Calculator (Ukraine) were not adjusted as in the app guidelines, but we took mean reference evapotranspiration values computed in the app.

The study was conducted for the period with mean daily air temperature above zero in 2021 (precondition for successful use of ETo Calculator (Ukraine), which can compute reference evapotranspiration only if air temperature is above zero). There were 322 such days in Kherson oblast, 321 in Mykolaiv, 300 in Dnipropetrovsk, 303 in Cherkasy, 299 in Chernihiv, and 325 in Uzhhorod (Zakarpattia), respectively. Each region was chosen to represent general climatic conditions of different zones of the country: Kherson – Dry Steppe zone; Mykolaiv – Southern Moderately Dry Steppe zone; Dnipro – Northern Steppe zone; Cherkasy – Forest Steppe zone; Chernihiv – Polissia; Uzhhorod (Zakarpattia) – Forest zone. Ukraine territory zoning was taken according to the study [16]. The schematic image of the study location is presented in the Figure 1.

Statistical comparison included evaluation of such indices as R, R^2, RMSE, MAE, and MAPE. Common procedures were used to calculate the mentioned statistical parameters

 doi:10.20944/preprints202206.0337.v1

using MS Excel 365 table processor [17–22]. The following equations (1–6) were utilized in the statistical calculations:

$$R_{XY} = \frac{\sum_1^N (x_i - \bar{x})(y_i - \bar{y})}{(N-1) s_X s_Y} \quad (1)$$

where: s_X, s_Y – standard deviations for X and Y, respectively; N – number of data; x_i, y_i – values of the studied parameters in the pair; $\bar{x}, \bar{y}$ – mean values for X and Y, respectively.

$$MSE = \frac{1}{n} \sum_{i=1}^{n} \left(Y_i - \hat{Y}_i\right)^2 \quad (2)$$

where: n – number of data; $Y_i - \hat{Y}_i$ – difference between the real and forecasted values.

$$RMSE = \sqrt[2]{MSE} \quad (3)$$

$$MAPE = \frac{100\%}{n} \sum_{t=1}^{n} \left| \frac{A_t - F_t}{A_t} \right| \quad (4)$$

where: At – the real value of the parameter; Ft – forecasted value of the parameter.

$$MAE = \frac{\sum_{i=1}^{n} |e_i|}{n} \quad (5)$$

$$|e_i| = |y_i - x_i| \quad (6)$$

where: y_i – forecasted value of the parameter; x_i – the real value of the parameter.

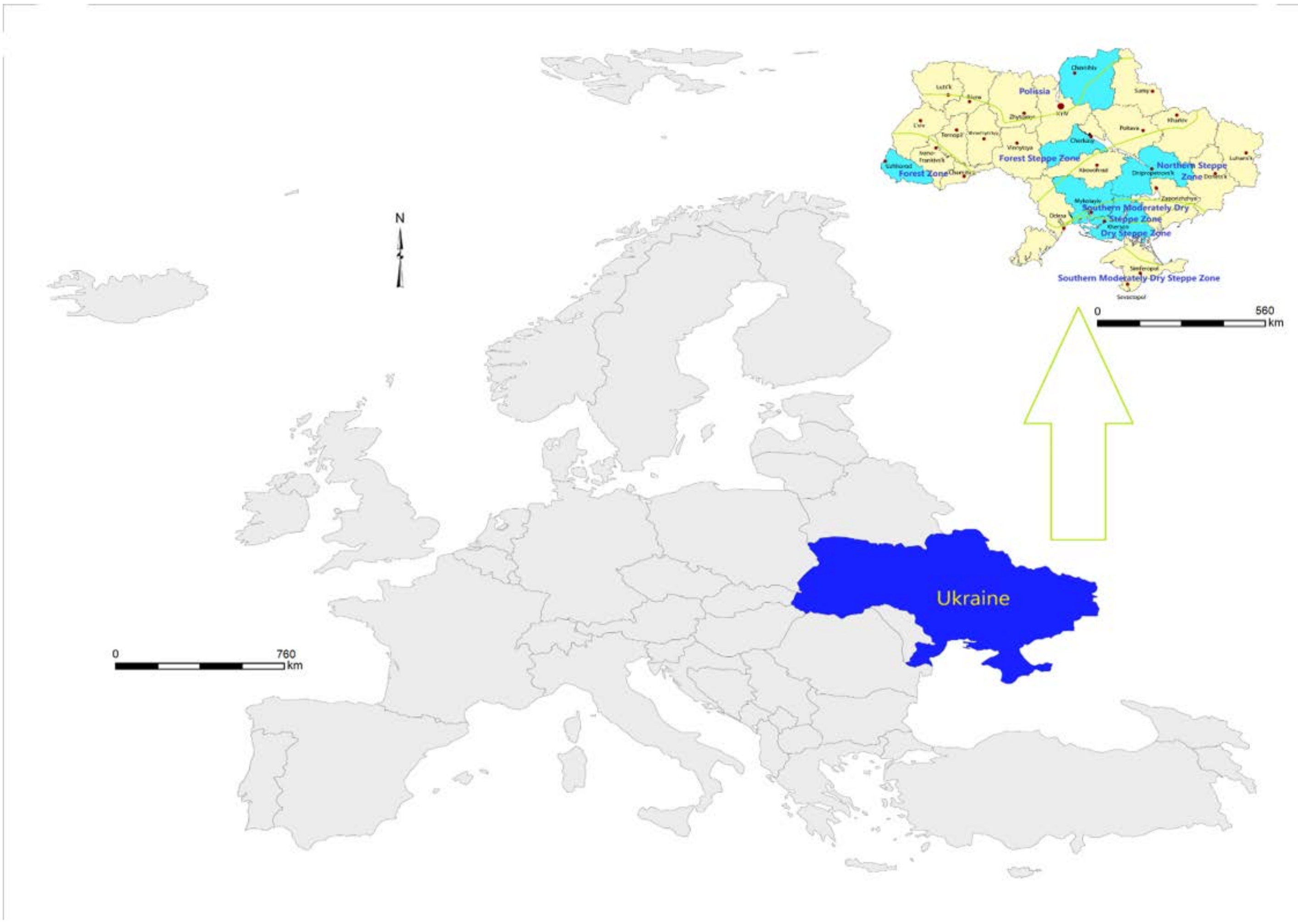

Figure 1. Location of the study regions on the map of Europe and the map of Ukraine.

Visual approximation was performed in MS Excel 365 to assist visual assessment of ETo estimation accuracy and simplify the process of finding the pairs with the highest discrepancy in the index computation.

3. Results

Statistical comparison between Penman-Monteith and the studied temperature-based method for ETo assessment testifies about relatively good performance of the latter. The values of correlation and determination coefficients by all the studied locations prove high quality of fitting (Table 1). Although RMSE and MAE values are far from ideality, one must admit that they are lower than in the testing run of alternative mobile app EVAPO with average RMSE of 0.95 mm [9]. Moreover, it should be stressed that the fore quoted estimation was performed in raw run without previous adjustment of ETo Calculator (Ukraine) computations to relative air humidity and windspeed.

Visual approximation of the ETo Calculator (Ukraine) calculations is presented in the Figure 2. It is evident that the highest discrepancy between the studied methods of reference evapotranspiration assessment is observed in Cherkasy region, while the slightest ones – in Mykolaiv and Kherson (the driest regions among the studied). This fact tells us that there is an influential geographical component in the model of ETo Calculator (Ukraine) owing to which the accuracy of ETo estimation may vary significantly between the regions of the country.

To sum up, the best performance of the tested mobile app is recorded for Mykolaiv oblast of Ukraine (Southern Moderately Dry Steppe zone), while the worst performance is associated with Dnipropetrovsk oblast (Northern Steppe zone) because of the highest values of deviations RMSE and MAE.

Table 1. Statistical indices of ETo Calculator (Ukraine) mobile app accuracy comparing to Penman-Monteith method of reference evapotranspiration assessment.

Statistical index	Region of Ukraine					
	Kherson	**Mykolaiv**	**Dnipropetrovsk**	**Cherkasy**	**Chernihiv**	**Uzhhorod (Zakarpattia)**
R	0.93	0.93	0.92	0.91	0.92	0.91
R^2	0.86	0.87	0.84	0.83	0.86	0.82
RMSE (mm)	0.75	0.74	0.81	0.80	0.74	0.77
MAE (mm)	0.61	0.60	0.70	0.64	0.62	0.63
MAPE (%)	18.58	18.07	20.69	20.86	22.22	25.50

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 June 2022 doi:10.20944/preprints202206.0337.v1

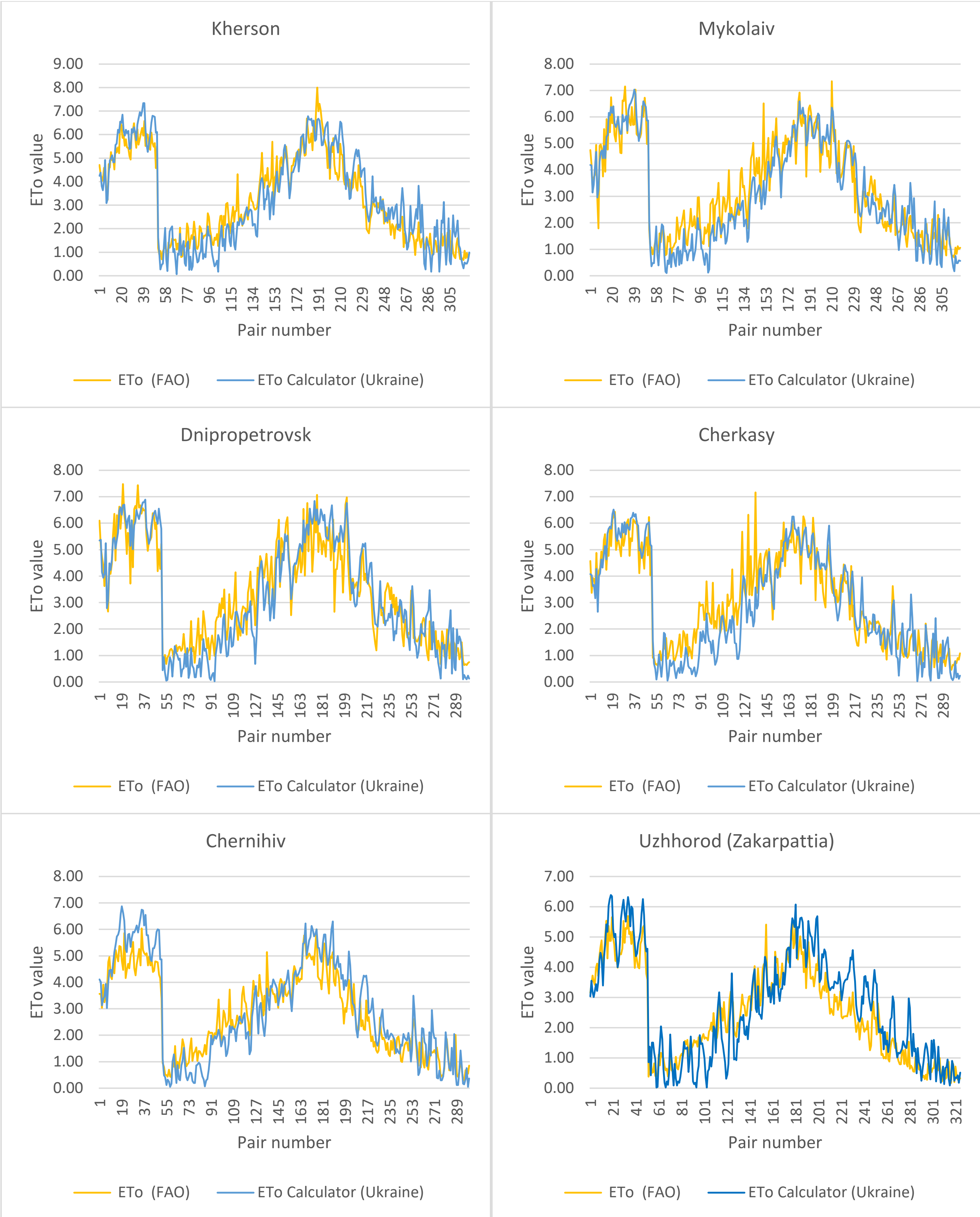

Figure 2. Reference evapotranspiration (mm/day) comparison between the standard FAO Penman-Monteith (Sherzod Rusmetov adaptation) and ETo Calculator (Ukraine) method by the studied regions of Ukraine.

4. Discussion

Although direct lysimetric method is undebatable superior to all other indirect methods of ETo assessment, there is a lack of lysimetric stations available, and therefore, it is mainly used in scientific research purposes for validation and calibration of the computation methods for reference evapotranspiration estimation [23–25]. For example, the standard FAO method of Penman-Monteith equation has been validated and calibrated using lysimetric data, thus, its performance is reckoned to be the best one among the other indirect computational approaches for ETo assessment [26–27].

However, the requirement of great number of meteorological inputs, which are often hardly accessible, limits practical implementation of Penman-Monteith-based assessment of reference evapotranspiration. Seeking for cutting the number of inputs resulted in the development of alternative approaches for ETo calculation, the most popular among which are Hargreaves and Makkink equations [28–30]. The above methods use more common weather data from meteorological stations; however, some data (e.g., extra-terrestrial radiation amount) are still inaccessible for certain territories due to the lack of weather stations and specific recording equipment [31]. Mean air temperature remains the easiest meteorological index to obtain through direct measurement in the field or even using weather data provided by forecast services. Therefore, reference evapotranspiration calculations based on air temperature have the highest perspective for practical implementation by farmers.

At the same time, new simplified approaches must be accurate. Of course, it is unfair to demand for 100% accuracy: even standardized Penman-Monteith equation is not flawless and in some environmental conditions it fails to provide reliable reference evapotranspiration assessment for irrigation management without previous calibration [32]. Therefore, high accuracy and reliability is desirable, but it might strongly depend on environment. Thus, it is difficult to develop one tool for ETo assessment in any region of the planet with similar efficiency in different climatic zones. ETo Calculator (Ukraine) takes this fact into account and proposes different models for reference evapotranspiration estimation even within the boarders of one country. Of course, it could be considered a drawback that the app is suitable just for in-Ukraine calculations, but this grants the highest possible accuracy of calculations in the zones, which are embraced in the mobile app.

There are some other software options for ETo assessment. For example, computer-based programs produced by FAO – Eto Calculator, CROPWAT (perhaps, the most popular and reliable ones, however, unsuitable for field conditions because of the absence of mobile apps). If FAO software is too complicated, one can use software based on alternative calculation methods such as DailyET [33] or one of the latest developments in this field for the calculations using limited weather data [8]. And if one needs ETo forecasting, FORETo software, which is based on artificial intelligence systems, will be of a great interest, even considering relatively high RMSE of 0.98 mm [34].

Although all the above-mentioned software has its advantages, the common drawback is that none of it is portable and requires PC for calculations. In this regard, ETo Calculator (Ukraine) is the only mobile app product with relatively high accuracy of operational reference evapotranspiration estimation for Ukrainian farmers.

5. Conclusions

The results of the comparative statistical analysis between ETo calculated using Penman-Monteith method and simplified computations in ETo Calculator (Ukraine) mobile app testify about relatively high accuracy and correspondence between both methods in the estimation of the agrometeorological index. Therefore, ETo Calculator (Ukraine) mo-

 doi:10.20944/preprints202206.0337.v1

bile app could be recommended for use in operational irrigation management for Ukrainian farmers if other options are too much complicated or require too much input data. Although the app accuracy was tested in raw run mode without adjustments, it seems like even such use is justified. However, it is felt that further improvements of the computation method are required. It is highly likely that introduction of ANN-based approach will enhance the quality of ETo assessment in the app.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Falkenmark, M. Growing water scarcity in agriculture: future challenge to global water security. *Philos. Trans. Royal Soc. A* **2013**, *371*, 20120410.
2. Peng, Y.; Xiao, Y.; Fu, Z.; Dong, Y.; Zheng, Y.; Yan, H.; Li, X. Precision irrigation perspectives on the sustainable water-saving of field crop production in China: Water demand prediction and irrigation scheme optimization. *J. Clean. Prod.* **2019**, *230*, 365–377.
3. Sentelhas, P.C.; Gillespie, T.J.; Santos, E.A. Evaluation of FAO Penman–Monteith and alternative methods for estimating reference evapotranspiration with missing data in Southern Ontario, Canada. *Agric. Water Manage*. **2010**, *97*, 635–644.
4. Kashyap, P.S.; Panda, R.K. Evaluation of evapotranspiration estimation methods and development of crop-coefficients for potato crop in a sub-humid region. *Agric. Water Manage*. **2001**, *50*, 9–25.
5. Tabari, H.; Grismer, M.E.; Trajkovic, S. Comparative analysis of 31 reference evapotranspiration methods under humid conditions. *Irrig. Sci*. **2013**, *31*, 107–117.
6. Beven, K. A sensitivity analysis of the Penman-Monteith actual evapotranspiration estimates. *J. Hydrol*. **1979**, *44*, 169–190.
7. Howell, T.A.; Evett, S.R. The Penman-Monteith method. Evapotranspiration: Determination of Consumptive Use. In *Water Rights Proceedings, Continuing Legal Education in Colorado*; Inc. Denver, Colorado, USA, 2004.
8. Gocic, M.; Trajkovic, S. Software for estimating reference evapotranspiration using limited weather data. *Comp. Electr. Agric*. **2010**, *71*, 158–162.
9. Maldonado Jr., W.; Borges Valeriano, T.T.; de Souza Rolim, G. EVAPO: A smartphone application to estimate potential evapotranspiration using cloud gridded meteorological data from NASA-POWER system. *Comp. Electr. Agric*. **2019**, *156*, 187–192.
10. Lykhovyd, P.V.; Piliarska, O.O.; Biliaieva, I.M. The possibilities of using mobile application EVAPO for operational assessment of evapotranspiration in the field conditions. *Tavr. Sci. Herald*. **2020**, *116*, 10–14.
11. Vozhehova, R.A.; Lykhovyd, P.V. Evaluation of the accuracy of evapotranspiration computation in the EVAPO mobile application. *Techn. Technol. Asp. Dev. Test. New Mach. Technol. Agric. Ukr*. **2021**, *43*, 120–125.
12. Lykhovyd, P. Reference evapotranspiration calculation in the zone of Ukrainian Polisia using air temperature. *Biosci. Biotech. Res. Commun*. **2020**, *13*, 1834–1836.
13. Lykhovyd, P.V. Assessment of reference evapotranspiration in the South of Ukraine by air temperature. *Intern. J. Emerg. Technol*. **2020**, *11*, 278–282.
14. Lipinsky, V.M.; Diachuk, V.A.; Babichenko, V.M. *Climate of Ukraine*; Rayevsky Publishing House: Kyiv, Ukraine, 2003.
15. Galik, O.I.; Basiuk, T.O. *Guidelines "Reference book on Ukrainian climate" for conduction of practical, computation, diploma and master's degree work for the students of full and correspondent education forms of life sciences specialties of the NUWEEM*; Rivne, Ukraine, 2014.
16. Polupan, M.I.; Solovei, V.B.; Velychko, V.A. *Classification of the Soils of Ukraine*; Agrarna nauka: Kyiv, Ukraine, 2005.
17. Hinkle, D.E.; Wiersma, W.; Jurs, S.G. Correlation: A measure of relationship. *Appl. Stat. Behav. Sci*. **1998**, *4*, 105–131.
18. Neter, J.; Wasserman, W.; Kutner, M.H. *Applied Linear Statistical Models*. Irwin, Chicago, USA, 1996.
19. Pontius, R.G.; Thontteh, O.; Chen, H. Components of information for multiple resolution comparison between maps that share a real variable. *Environ. Ecol. Stat*. **2008**, *15*, 111–142.
20. Willmott, C.J.; Matsuura, K. On the use of dimensioned measures of error to evaluate the performance of spatial interpolators. *Intern. J. Geo. Inform. Sci*. **2006**, *20*, 89–102.
21. Willmott, C.J.; Matsuura, K. Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. *Clim. Res*. **2005**, *30*, 79–82.
22. De Myttenaere, A.; Golden, B.; Le Grand, B.; Rossi, F. Mean absolute percentage error for regression models. *Neurocomputing*. **2016**, *192*, 38–48.
23. Xu, C.Y.; Chen, D. Comparison of seven models for estimation of evapotranspiration and groundwater recharge using lysimeter measurement data in Germany. *Hydrol. Process*. **2005**, *19*, 3717–3734.
24. Malone, R.W.; Bonta, J.V.; Stewardson, D.J.; Nelsen, T. Error analysis and quality improvement of the Coshocton weighing lysimeters. *Trans. ASAE* **2000**, *43*, 271–280.

25. Cruz-Blanco, M.; Galivan, P.; Santos, C.; Lorite, I.J. Assessment of reference evapotranspiration using remote sensing and forecasting tools under semi-arid conditions. *Intern. J. Appl. Earth Observ. Geoinf.* **2014**, *33*, 280–289.
26. Berengena, J.; Gavilán, P. Reference evapotranspiration estimation in a highly advective semiarid environment. *J. Irrig. Drain. Eng. ASCE* **2005**, *131*, 147–163.
27. López-Urrea, R.; Martín De Santa Olalla, F.; Fabeiro, C.; Moratalla, A. Testing evapotranspiration equations using lysimeter observations in a semiarid climate. *Agric. Water Manage*. **2006**, *85*, 15–26.
28. Pereira, A.R.; Pruitt, W.O. Adaptation of the Thornthwaite scheme for estimating daily reference evapotranspiration. *Agric. Water Manage*. **2004**, *66*, 251–257.
29. Gavilán, P.; Berengena, J.; Allen, R.G. Measuring versus estimating net radiation and soil heat flux: impact on Penman–Monteith reference ET estimates in semiarid regions. *Agric. Water Manage*. **2006**, *89*, 275–286.
30. De Bruin, H.A.R.; Trigo, I.F.; Jitan, M.A.; Temesgen, E.N.; van der Tol, C.; Gieske, A.S.M. Reference crop evapotranspiration derived from geo-stationary satellite imagery – a case study for the Fogera flood plain, NW-Ethiopia and the Jordan Valley, Jordan. *Hydrol. Earth Syst. Sci. Discuss*. **2010**, *14*, 2219–2228.
31. Voogt, M.P. Meteolook, A Physically Based Regional Distribution Model for Measured Meteorological Variables. MSc Thesis, TU Delft, 2006.
32. Vozhehova, R.A.; Lavrynenko, Y.O.; Kokovikhin, S.V.; Lykhovyd, P.V.; Biliaieva, I.M.; Drobitko, A.V.; Nesterchuk, V.V. Assessment of the CROPWAT 8.0 software reliability for evapotranspiration and crop water requirements calculations. *J. Water Land Devel*. **2018**, *39*, 147–152.
33. Hess, T.M. *Potential Evapotranspiration* [DAILYNET]. Silsoe College, UK, 1996.
34. Ballesteros, R.; Ortega, J.F.; Moreno, M.A. FORETo: New software for reference evapotranspiration forecasting. *J. Arid Environ*. **2016**, *124*, 128–141.