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ESTIMATION OF THE ACCURACY OF THE CALCULATION OF REFERENCE AND ACTUAL EVAPOTRANSPIRATION BASED ON VIRTUAL WEATHER STATION DATA FOR POLISSYA REGION OF UKRAINE

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Abstract: *This article evaluates the accuracy of calculating reference and actual evapotranspiration using Virtual Visual Crossing Weather Data (VCWD) and automatic iMetos Base meteorological station data in Polissya, Ukraine. The study confirmed the feasibility of calculating ETo and ETc using VCWD meteorological data. The ETo calculation is 86,1 % accurate, with an RMSE and SEE error of 0,76 and 0,49 mm, respectively. The ETo calculation with correction factors for meteorological data increases its accuracy by 1,4 %, and the RMSE error decreases by 0,08 mm. The most accurate calculations were obtained using a correction factor of 1,1 to the calculated ETo. With the correction factor applied, the ETo determination accuracy is 88,9 %, with RMSE and SEE errors of 0,58 and 0,54 mm, respectively. The ETo data from VCWD were obtained with satisfactory accuracy; the largest errors in the MAPE, RMSE, and SEE were 20,4 %, 1.09 mm, and 1,02 mm, respectively. For 2023–2024, the FEA, RMSE, and SEE errors for ETo calculated from VCWD meteorological data, accounting for the 1,1 correction factor, were 10,0–12,2 %, 0,55–0,60, and 0,51–0,55 mm, respectively. During the research period, the MAPE, RMSE, and SEE errors for this variant were 9,0 %–14,0 %, 0,52–0,63 mm, and 0,34–0,56 mm, respectively. The calculation of absolute errors in determining ETo confirms that the most reliable data of reference evapotranspiration are obtained using the correction factor. This option resulted in the smallest average absolute error by years of research, which is 5 mm, and in 2024 this error was 0. In terms of months, the smallest absolute error of 2 mm was observed in May and August, and the largest –13 mm in September.*

The results of the calculations of actual evapotranspiration (ETc) of crops showed that using a correction factor of 1,1 to ETo increases the accuracy of ETc calculations. The mean absolute relative error (MAPE) decreased by 2,1 % for all crops, and the root mean square error (RMSE) decreased by 0,16, 0,15, and 0,09 mm for corn, potatoes, and blueberries, respectively. The average absolute ETc errors by year of research using a correction factor of 1,1 for ETo were 15,7, and 11 mm for corn, potatoes, and blueberries, respectively. In May, June, and July, the calculated ETc for corn seed was 11,6, and 8 mm lower than the actual values. In August and September, it was 1 and 9 mm higher, respectively. This trend in the errors distribution is also observed for potatoes and blueberries.

Keywords: *virtual weather station, reference evapotranspiration, actual evapotranspiration, corn, potatoes, blueberries, accuracy, IEA errors, RMSE errors, and SEE errors*

Relevance of the study. The Penman – Monteith method (FAO56-PM) is widely used in irrigation management today. While the use of various meteorological data is an advantage of this method, it is also a disadvantage because not all the necessary data are always available. This is because not all the meteorological data necessary for calculating reference evapotranspiration (ETo) using the Penman-Monteith method are always available. ETo is most often calculated using automated weather stations (AWS), but these must be equipped with all the necessary climate sensors, which increases their cost, which is already considerable. The sensors used at AWS must be periodically checked and have a service life of 3–5 years. During operation, it is necessary to monitor the sensors and clean them periodically, as well as monitoring the station's power supply, especially in winter. In the absence of communication, there is a risk of data loss, and the range of the AWS is up to 5 km or 8 thousand hectares.

Given the high cost of AWS and all its shortcomings, the calculation of ETo by the Penman-Monteith method using data from virtual weather stations (VWS) is of practical importance. The Visual Crossing Weather Data (VCWD) virtual weather station was chosen to calculate the ETo. It provides easy access to hourly or daily climate data for the entire world, including forecast data for the next 15 days. Its archive includes more than 50 years of global weather history. In addition to the usual meteorological indicators, such as temperature and relative humidity, wind speed, precipitation, powerful features such as solar radiation and energy, degree days, reference evapotranspiration, and weather forecast are available. All data from the site is available for download via the weather data request page and the weather API. The datasets are displayed in a table, which is available in several formats. One of the powerful features of VCWD is the ability to import data into most business intelligence systems, Excel and others for further processing.

Analysis of recent research and publications. Much attention has been paid to the issue of determining crop evapotranspiration (ETc) and its accuracy [1, 2]. Accurate estimation of reference evapotranspiration (ETo) is crucial for determining crop water requirements. However, the lack of appropriate weather stations, especially in arid areas, can negatively affect the accuracy of ETc estimates. Studies conducted in the Persian Gulf and Gulf of Oman basin (western and southwestern Iran) [3] to evaluate the performance of three datasets ERA5, ERA5-Land, and WaPOR for ET estimation emphasize that ERA5 demonstrates better overall performance compared to other datasets in ET estimation. However, WaPOR performed better at high-altitude stations with heterogeneous topography than the reanalysis of ERA5 and ERA5-Land. Thus, none of the datasets could provide accurate ETo estimates for all stations within the basin. Studies evaluating the accuracy of the daily reference evapotranspiration [4] calculated using NASA POWER reanalysis products in the Mediterranean climate (southern Portugal) indicate that when using the raw NASA POWER datasets, good accuracy between the calculated and observed ETo was observed at most locations. The LSA-SAF products [5] showed a high potential for accurate ETo calculation for continental Portugal, but low accuracy for the Azores. The study [6] evaluated the data quality of GLDAS-1, NLDAS-2, CFSv2, gridMET, RTMA, and NDFD weather products for ETo calculation. The results were compared with 103 weather stations located in well-moistened areas of the United States. ETo and the climate data used to calculate it were compared. The meteorological datasets from virtual weather stations overestimate the reference evapotranspiration obtained from ground-based weather stations, with an average deviation ranging from 12 to 31 %. The overestimation is mainly due to overestimation of air temperature, shortwave radiation, wind speed, and underestimation of relative humidity. These results indicate that virtual weather station data should be carefully evaluated before replacing agricultural weather station data. Correction procedures can make virtual weather station data more suitable for ETo calculation. Current evapotranspiration estimation methods are typically based on ETo calculations using data from scattered weather stations, many of which may be located in partially or totally dry environments with no evaporation. Such data and the calculated ETo may suffer from a shift in aridity relative to the ETo characteristic of irrigated conditions. Study [2] developed an algorithm for processing climate data to quantify the impact of surface aridity on the calculation of reference evapotranspiration. The conditioning algorithm is based on standard equations of the surface energy balance and the relationship between the flow and profile of air masses, which can be applied to both point weather station data and virtual weather station weather datasets. The calculation of the reference evapotranspiration using the Penman-Monteith equation requires extended weather data, but the relevant datasets are often unavailable, incomplete, or of uncertain quality. The study [7] discusses computational procedures related to the prediction of missing variables from temperature, i.e., the RM temperature approach (RMTA) and the estimation of ETo using the Hargreaves-Samani (HS) equation. Since the results of ETo in the HS equation depend almost linearly on air temperature, the RMT approach, which uses climate data estimates, is able to mitigate these temperature effects. An obvious advantage of the RMT approach is that it allows the use of available weather data in combination with estimates of missing data, which results in more accurate ETo calculations.

The calculation of actual evapotranspiration (ETa) usually requires the measurement of several atmospheric and evaporative surface variables. In a linear generalized model (GLM), the dependent variable is linearly related to the factors and co-variables through functional relationships. To calculate the daily actual evapotranspiration (ETa) of barley crops in the eastern Argentine Pampa, data from the meteorological and energy balance were used [8]. A linear generalized model (GLM) was obtained to calculate ETa from using meteorological data measured at the stations. The model has shown good efficacy and can be applied and tested on other large plains.

Quantifying water consumption by the agricultural sector requires continuous monitoring at different spatial scales from one hectare to a basin. However, providing spatially distributed information for large areas makes the use of on-site measuring devices impossible. Earth observation satellites and remote sensing techniques offer an effective alternative in assessing water use. However, in order to implement an operational monitoring system based on remote sensing data, it is necessary to establish approaches with reliable protocols to obtain information at the required spatial and temporal scale [9]. Landsat imagery combined with the METRIC model is used in the EEFlux program to estimate actual evapotranspiration in irrigated areas, with uncertainty as to whether the results are sufficiently accurate at local scales. A study to assess the accuracy of the obtained indicators was conducted for irrigated areas in the northern state of Sinaloa (Mexico) from 1995 to 2018 [10], comparing temporal and spatial estimates using Landsat images and the METRIC model with locally measured weather data and EEFlux. The results of the analysis confirm differences that are closely related to crop growth, with a daily average absolute error of 1.17 mm/day. The spatial analysis showed that when using only arable land pixels without non-arable land pixels in EEFlux, R^2increases from 0,36 to 0,73 and RMSE decreases from 2,52 to 1,98 mm/day.

The aim of the study was to assess the accuracy of the calculations of reference (ETo) and actual (ETs) evapotranspiration according to the data of the virtual weather station Visual Crossing Weather Data (VCWD) and compare them with the actual data obtained from the automated Internet weather station iMetos base.

Materials and methods. The meteorological data for this study were obtained from VWS Visual Crossing Weather Data [11] for the period 2023-2024 and from AWS iMetos Base from Pessl Instruments [12], which is located at the experimental site of LLC "Agrofirma Kyivska", Makovyshche village, Makariv district, Kyiv region (50.4574°N, 29.8949°E).

To analyze and calculate the reference evapotranspiration (ET_0), the average daily meteorological data: average air temperature (Ta) and dew point (Tdew), wind speed (u_2) and total solar radiation (Rs) were used. The reference evapotranspiration, based on VCWD meteorological data, was calculated using the Penman-Monteith FAO56-PM method [13]:

$$ET_0 = \frac{0,408\Delta\left(R_n - G\right) + \gamma \frac{900}{T+273} u_2 \left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0,34 u_2\right)}. \quad (1)$$

where ET_0 is the reference evapotranspiration, mm/day; *Rn* is the net radiation on the plant surface, MJ/m^2-day; *G* is the density of the soil heat flux, MJ/m^2-day; *Ta* is the average daily air temperature at a height of 2 m, °C; $u_{(2)}$ is the wind speed at a height of 2 m, m/s; $e_{(s)}$ is the saturated vapor pressure, kPa; $e_{(a)}$ $_{is}$the actual pressure, kPa; Δ is the gradient of the vapor pressure curve, kPa/° C; γ is the psychometric constant, kPa/C.

To calculate $e_s$and $e_{(a)}$ the mean air temperature and dew point values were used, respectively. The average wind speed was calculated for a height of 2 m. The other parameters included in formula (1) were calculated according to the FAO56-PM methodology [13].

The calculated reference evapotranspiration was compared with the actual ET_0 obtained from the AWS iMetos database.

Crop evapotranspiration was calculated using the formula [13]:

$$ET_C = ET_0 \cdot K_C . \quad (2)$$

where ET_C is evapotranspiration, mm/day; K_C is the crop coefficient.

Tossess the accuracy of the calculations of the reference and actual evapotranspiration, the MAPE (Mean Absolute Percent Error), RMSE (Root Mean Square Error), SEE (Standard Error of Estimate), and AE (Absolute Error) were determined [14–17]:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{x-y}{x}\right| \cdot 100\% . \quad (3)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x-y\right)^2} . \quad (4)$$

$$SEE = \sqrt{\frac{1}{\left(n-2\right)}\left[\left(y-\bar{y}\right)^2 - \frac{\left[\Sigma\left(x-\bar{x}\right)\left(y-\bar{y}\right)\right]^2}{\Sigma\left(x-\bar{x}\right)^2}\right]}. \quad (5)$$

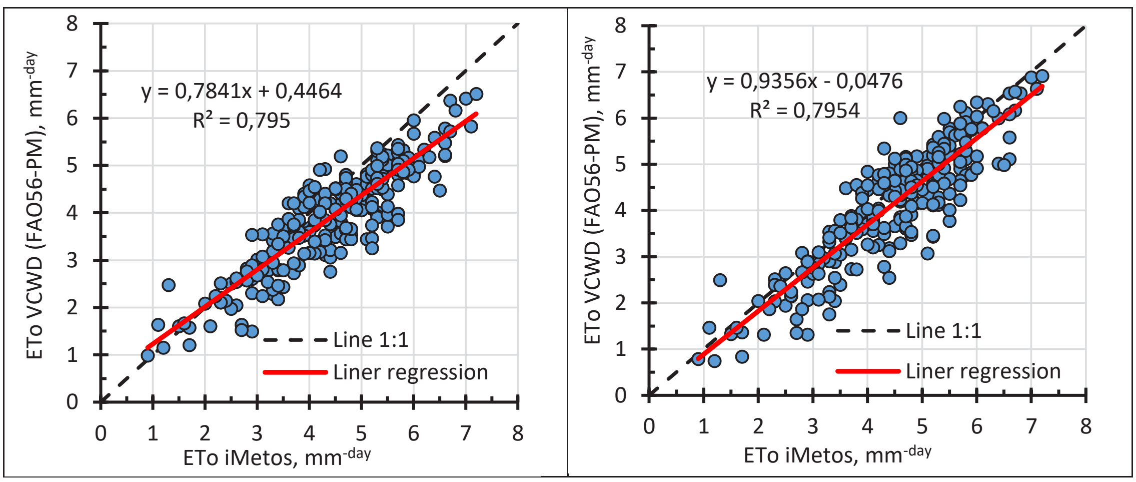
$$AE = x - y . \quad (6)$$

$$Accuracy(\%) = 100\% - MAPE(\%) \quad (7)$$

where x – $ET_{(0)}$ or ET_C according to the iMetos Internet weather station; y – $ET_{(0)}$ or ETc calculated according to VCWD (FAO56-PM); n – sample size.

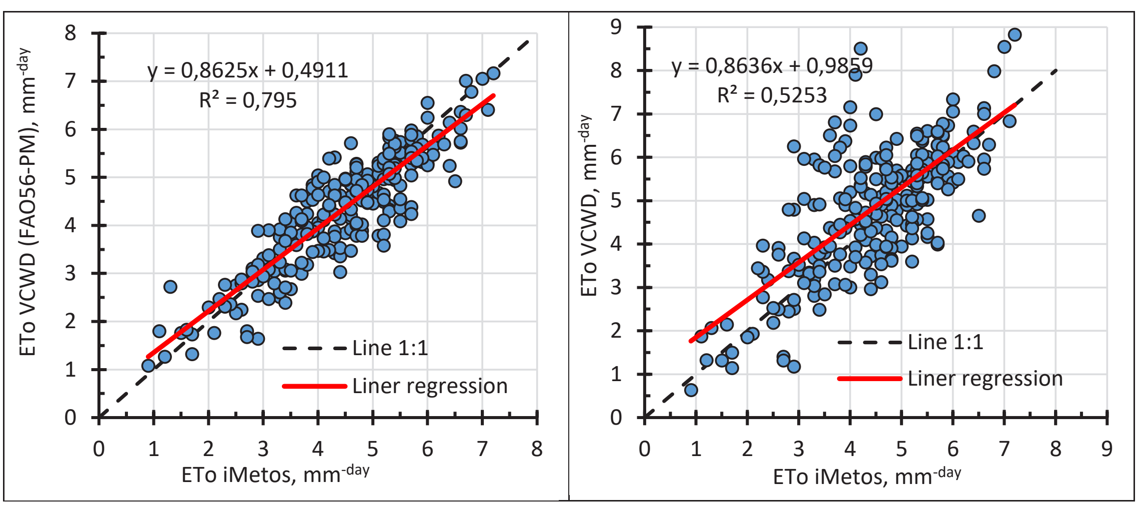
Results of the study. A comprehensive assessment of meteorological data obtained from the Visual Crossing Weather Data (VCWD) virtual weather station for the conditions of Polissya of Ukraine, which are necessary for the calculation of ETo, was carried out in previous studies [18].

The analysis of the calculation of the reference evapotranspiration by the Penman-Monteith method (FAO56-PM) using meteorological data from Visual Crossing Weather Data indicates that the result obtained is of good accuracy. Thus, when using meteorological data from VCWD (Fig. 1a), the calculation accuracy is 86,1 %, and the RMSE and SEE errors are 0,76 and 0,49 mm, respectively (Table 1). The calculation of ETo taking into account the correction factors for meteorological data (Fig. 1b), which we obtained earlier, increases the accuracy of ETo calculations by 1,4 %, and the RMSE error decreased by 0.08 mm. The SEE error, on the contrary, increased by 0,10 mm. The most accurate calculations were obtained using the correction factor to the calculated ETo according to VCWD meteorological data, which is 1,1 (Fig. 1c). Thus, taking into account the correction factor, the accuracy of determining the ETo is 88,9 %, and the RMSE and SEE errors, respectively, are 0,58 and 0,54 mm. In the VWS Visual Crossing Weather Data setup menu, there



a) ETo bt VCWD meteorological data

b) ETo with correction factors to VCWD meteorological data



c) ETo according to meteorological data VCWD with a correction factor of 1.1

d) ETo by the VCWD data

Fig. 1. Regression analysis for verification of the calculated ETo by the Penman-Monteith method using VCWD meteorological data

1. MAPE, RMSE, and SEE for the calculated ETo (mm) using the Penman-Monteith method based on VCWD meteorological data (by observation periods)

Observation period	MAPE error				RMSE error				SEE error			
	1	2	3	4	1	2	3	4	1	2	3	4
sir	13,9	12,5	11,1	20,4	0,76	0,68	0,58	1,09	0,49	0,59	0,54	1,02
2023	14,9	14,1	10,0	13,6	0,78	0,75	0,55	0,74	0,46	0,62	0,51	0,70
2024	12,9	10,9	12,2	27,2	0,74	0,60	0,60	1,35	0,50	0,54	0,55	1,19
May	14,5	13,6	9,3	12,1	0,83	0,82	0,58	0,74	0,52	0,69	0,57	0,58
June	16,2	15,6	11,8	11,9	0,87	0,80	0,62	0,64	0,51	0,66	0,56	0,61
July	15,2	13,5	11,0	14,5	0,88	0,74	0,63	0,84	0,51	0,65	0,56	0,86
August	11,2	9,4	9,0	20,0	0,66	0,57	0,52	1,09	0,46	0,55	0,50	0,90
September	12,6	10,7	14,0	43,9	0,48	0,44	0,52	1,78	0,31	0,34	0,34	0,64

1 – ETo according to VCWD meteorological data; 2 – ETo with correction factors for VCWD meteorological data; 3 – ETo according to VCWD meteorological data with correction factor 1,1; 4 – ETo according to VCWD data.

is a paid option for calculating ETo, which costs $150 per month. The verification of ETo data obtained from VCWD and actual data (Fig. 1d) showed a satisfactory accuracy of the result. The errors of MARE, RMSE, and SEE were the largest and equaled to 20,4 %, 1,09, and 1,02 mm, respectively (Table 1).

For the study period of 2023-2024, the errors of MAPE, RMSE, and SEE for ETo calculated from VCWD meteorological data, taking into account the correction factor of 1,1, were 10,0–12,2 %, 0,55–0,60, and 0,51–0,55 mm, respectively. In terms of months of research, the errors of MAPE, RMSE, and SEE for this variant were in the range of 9,0–14,0 %, 0,52–0,63, and 0,34–0,56 mm, respectively.

The calculation of the absolute errors in determining ETo also confirms that the most reliable reference evapotranspiration data are obtained using a correction factor of 1,1 to ETo, which was determined from VCWD meteorological data. Thus, this variant resulted in the smallest average absolute error over the years of research, which is 5 mm. In 2024, this error was 0 (Table 2). In terms of months, the smallest absolute error of 2 mm was in May and August, and the largest was 13 mm in September.

When calculating ETo from VCWD meteorological data, the average absolute error over the years of research was 66 mm, and the use of correction factors for VCWD meteorological data in the calculations reduces the absolute error by 22 mm. In 2023 and 2024, the total ETo obtained from VCWD was 662 and 747 mm, respectively, which is 31 and 70 mm more than the actual values obtained from AWS iMetos (Table 2).

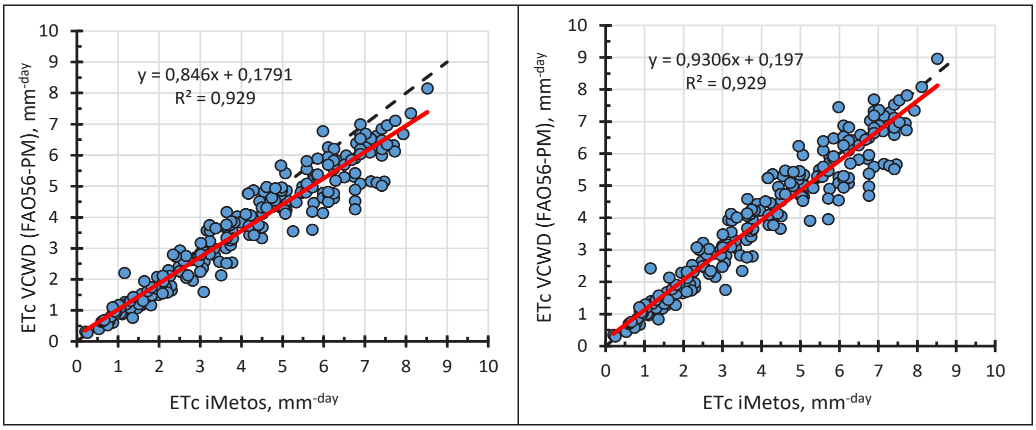
According to the results of calculations of evapotranspiration (ETc) of crops, it was found that the use of a correction factor of 1,1 to the calculated ETo increases the accuracy of ETc

2. Absolute errors of ETo, mm (by observation periods)

Observation period	Total ET_O, mm					Absolute error			
	iMetos	1	2	3	4	1	2	3	4
average	654	588	610	649	705	66	44	5	−51
2023	631	564	575	622	662	67	56	9	−31
2024	677	613	645	677	747	64	32	0	−70
May	129	114	121	128	133	15	8	2	−4
June	142	122	128	134	138	20	14	8	4
July	158	137	146	151	157	21	12	7	1
August	137	123	131	135	154	14	6	2	−17
September	88	92	84	101	123	−4	4	−13	−35

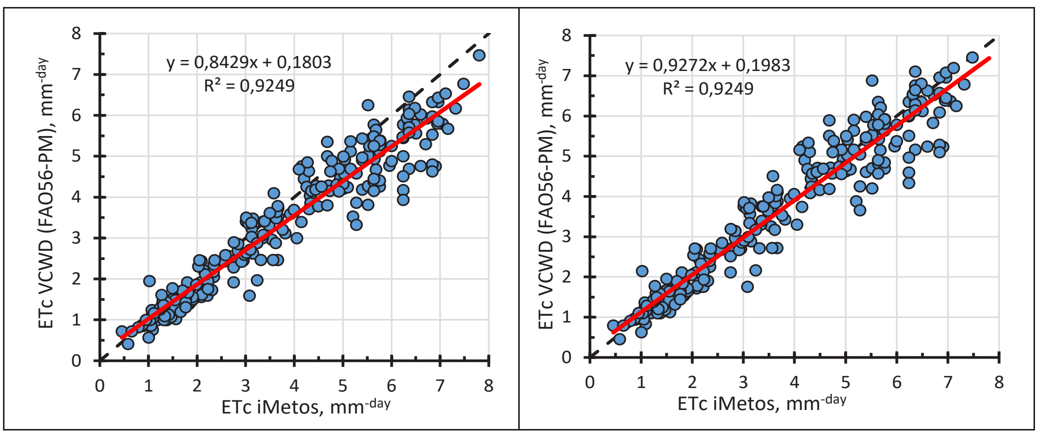
1 – ETo according to VCWD meteorological data; 2 – ETo with correction factors for VCWD meteorological data; 3 – ETo according to VCWD meteorological data with correction factor 1.1; 4 – ETo according to VCWD data.

calculations (Fig. 2–4, Table 3–4). Thus, the MAPE error decreased by 2,1 % for all crops. The RMSE errors for corn, potatoes and highbush blueberry decreased by 0,16, 0,15 and 0,09 mm, respectively. The SEE error, on the contrary, increased by 0,02–0,05 mm depending on the crop.



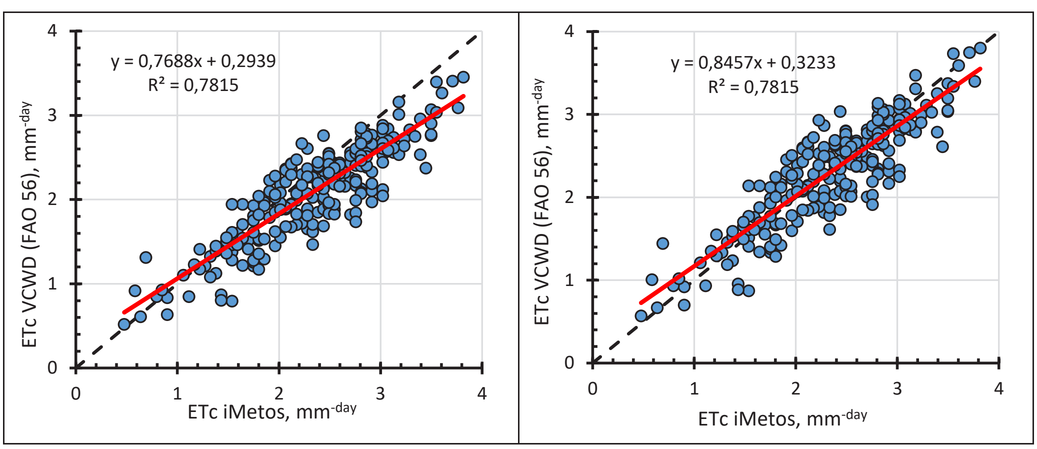
a) ETc= ETo-Ks б) ETc=1.1ETo-Ks

Fig. 2. Regression analysis for verification of the calculated seed corn ETc by the Penman – Monteith method



a) ETc= ETo-Ks б) ETc=1.1ETo-Ks

Figure 3. Regression analysis to verify the calculated ETc of potatoes by the Penman – Monteith method



a) ETc= ETo-Ks б) ETc=1.1ETo-Ks

Fig. 4. Regression analysis to verify the calculated ETc of highbush blueberry by the Penman – Monteith method

3. MAPE, RMSE and SEE for the calculated ETc (mm) by the Penman – Monteith method (by observation periods)

Observation period	MAPE error			RMSE error			SEE error		
	Corn	Potatoes	Highbush blueberry	Corn	Potatoes	Highbush blueberry	Corn	Potatoes	Highbush blueberry
average	13,7	13,7	13,7	0,74	0,69	0,40	0,50	0,47	0,27
2023 р.	14,2	14,2	14,2	0,73	0,69	0,40	0,46	0,43	0,25
2024 р.	13,1	13,1	13,1	0,76	0,70	0,39	0,54	0,50	0,27
May	14,2	14,2	14,2	0,28	0,29	0,44	0,16	0,18	0,28
June	16,1	16,1	16,1	0,65	0,61	0,46	0,37	0,35	0,27
July	15,0	15,0	15,0	1,07	0,99	0,46	0,61	0,56	0,27
August	10,5	10,5	10,5	0,75	0,69	0,33	0,54	0,49	0,25
September	12,7	12,7	12,7	0,24	0,24	0,25	0,17	0,16	0,17

4. MAPE, RMSE and SEE for the calculated ETs (mm), taking into account the correction factor of 1,1 by the Penman-Monteith method (by observation periods)

Observation period	MAPE error			RMSE error			SEE error		
	Corn	Potatoes	Highbush blueberry	Corn	Potatoes	Highbush blueberry	Corn	Potatoes	Highbush blueberry
average	11,6	11,6	11,6	0,58	0,54	0,31	0,55	0,52	0,29
2023	9,8	9,8	9,8	0,53	0,50	0,29	0,50	0,47	0,27
2024	13,3	13,3	13,3	0,62	0,58	0,33	0,59	0,55	0,30
May	9,3	9,3	9,3	0,17	0,20	0,31	0,17	0,20	0,30
June	11,8	11,8	11,8	0,47	0,45	0,33	0,41	0,39	0,30
July	11,0	11,0	11,0	0,77	0,71	0,33	0,67	0,62	0,30
August	9,5	9,5	9,5	0,64	0,59	0,28	0,59	0,54	0,27
September	16,0	16,0	16,0	0,36	0,34	0,30	0,19	0,18	0,19

The average absolute errors of ETc for the years of research using a correction factor of 1.1 to the calculated ETo for corn, potatoes and blueberries were 15,7 and 11 mm, respectively (Table 5). In May, June, and July, the calculated ETc for corn was 11, 6, and 8 mm less than the actual values, and in August and September, respectively, it was 1 and 9 mm more. This trend in the distribution of errors is also observed for potatoes and blueberries. According to the results of the research, the actual evapotranspiration of corn, potatoes and highbush blueberry in 2023–2024 was 514–535 mm, 443–472 mm and 310–345 mm, respectively. The obtained results confirm the high accuracy of determining ETc by the Penman-Monteith method using adapted crop coefficients and using the calculated ETo according to the data of the Visual Crossing Weather Data virtual meteorological station

5. Absolute errors of ETs, mm, taking into account the correction factor of 1,1 (by observation periods)

Observation period	ETc iMetos			ETc 1,1ETo VCWD (FAO56-PM)			Absolute error		
	Corn	Potatoes	Highbush blueberry	Corn	Potatoes	Highbush blueberry	Corn	Potatoes	Highbush blueberry
average	535	472	332	520	465	321	15	7	11
2023	527	452	314	508	447	302	19	5	12
2024	543	491	350	531	483	341	12	8	10
May	45	51	59	34	47	47	11	4	12
June	97	98	75	92	91	71	6	7	4
July	190	167	83	182	160	80	8	7	3
August	152	121	72	153	125	73	−1	−4	0
September	50	35	42	59	42	50	−9	−7	−8

Conclusions.

1. The results of the research confirmed the possibility of calculating ETo and ETc using the data of the virtual meteorological station Visual Crossing Weather Data.

2. To improve the accuracy of ETo calculation in the Polissya region of Ukraine, it is necessary to use a correction factor of 1,1. Taking into account the correction factor, the accuracy of determining ETo is the highest and amounts to 88,9 %, and the RMSE and SEE errors are the smallest and equaled to 0,58 and 0,54 mm, respectively.

3. According to the results of the verification, the ETo obtained from the VCWD and the actual one showed its satisfactory accuracy, which was 79,6 %, and the RMSE and SEE errors were the highest and amounted to 1,09 and 1,02 mm, respectively.

4. It was found that the use of a correction factor of 1,1 to the calculated ETo increases the accuracy of ETc calculations. Thus, the MAPE errors are reduced by 2,1 % for all crops, and the RMSE errors for corn at seeds, potatoes, and highbush blueberry are reduced by 0,16, 0,15, and 0,09 mm, respectively.

5. It was found that the average absolute errors of ETc over the years of research using a correction factor of 1,1 to the calculated ETo for corn for seed, potatoes, and blueberries were 15, 7 and 11 mm, respectively.

6. The obtained results confirm the high accuracy of determining ETc by the Penman-Monteith method using adapted crop coefficients and using the calculated ETo from the data of the Visual Crossing Weather Data virtual meteorological station

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ОЦІНКА ТОЧНОСТІ РОЗРАХУНКУ ЕТАЛОННОЇ ТА ФАКТИЧНОЇ ЕВАПОТРАНСПІРАЦІЇ ЗА ДАНИМИ ВІРТУАЛЬНОЇ МЕТЕОСТАНЦІЇ ДЛЯ УМОВ ПОЛІССЯ УКРАЇНИ

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Анотація. *У статті проведено оцінку точності розрахунку еталонної та фактичної евапотранспірації за даними віртуальної Visual Crossing Weather Data (VCWD) та автоматичної (iMetos Base) метеорологічної станції для умов Полісся України. За результатами досліджень підтверджено можливість розрахунку ETo та ETc з використанням метеорологічних даних VCWD, точність розрахунку ETo становить 86,1 %, а похибки RMSE та SEE відповідно становлять 0,76 та 0,49 мм. Розрахунок ETo з урахуванням поправочних коефіцієнтів до метеорологічних даних підвищує точність розрахунків ETo на 1,4 %, а похибка RMSE зменшується на 0,08 мм. Найбільш точні розрахунки отримуються з використанням поправочного коефіцієнту 1,1 до обчисленої ETo. З урахуванням поправочного коефіцієнту точність визначення ETo становить 88,9 %, а похибки RMSE та SEE відповідно становлять 0,58 та 0,54 мм. Дані ETo з VCWD отримано із задовільною точністю, а похибки MAPE, RMSE та SEE були найбільшими і відповідно становили 20,4 %, 1,09 та 1,02 мм. За 2023–2024 рр. досліджень похибки MAPE, RMSE та SEE для ETo розрахованої за метеорологічними даними VCWD з урахуванням поправочного коефіцієнту 1,1 відповідно становили 10,0–12,2 %, 0,55-0,60 та 0,51–0,55 мм. В розрізі місяців досліджень похибки MAPE, RMSE та SEE для цього варіанту відповідно знаходились в межах 9,0-14,0 %, 0,52–0,63 та 0,34–0,56 мм. Розрахунок абсолютних похибок визначення ETo підтверджує, що найбільш достовірні дані еталонної евапотранспірації отримуються з використанням поправочного коефіцієнту. За цього варіанту було отримано найменшу середню абсолютну похибку за роками досліджень, яка дорвнює 5 мм,а у 2024 році ця похибка дорівнювала 0. В розрізі місяців найменша абсолютна похибка 2 мм спостерігалась у травні та серпні, а найбільша -13 мм у вересні.*

За результатами розрахунків фактичної евапотранспірації (ETc) сільськогосподарських культур встановлено, що використання поправочного коефіцієнту 1,1 до ETo підвищує точність розрахунків ETc. Похибка MAPE знизилась на 2,1 % для всіх культур, а похибка RMSE для кукурудзи на насіння, картоплі та лохини щиткової відповідно знизились на 0,16, 0,15 та 0,09 мм.

Середні абсолютні похибки ETc за роками досліджень з використанням поправочного коефіцієнту 1,1 до ETo для кукурудзи на насіння, картоплі та лохини щиткової відповідно становили 15, 7, 11 мм. В травні, червні та липні розрахована ETc для кукурудзи на насіння відповідно на 11, 6 та 8 мм менше за фактичні значення, а в серпні та вересні відповідно на 1 та 9 мм більше. Така тенденція розподілу похибок спостерігається і для картоплі та лохини щиткової.

Ключові слова: *віртуальна метеостанція, еталонна евапотранспірація, фактична евапотранспірація, кукурудза, картопля, лохина щиткова, точність, похибки MAPE, похибки RMSE та похибки SEE*