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Estimation of natural water body's evaporation based on Class A pan measurements in comparison to reference evapotranspiration

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Abstract—A Class A pan (C) evaporation (E_p) study was conducted at the Agrometeorological Research Station of Keszthely, in the growing season of 2016. Some of the evaporation pans were implemented with freshwater aquatic macrophytes (*Myriophyllum* sp., *Potamogeton* sp., and *Najas* sp.) (P_s) and sediment covered bottom (S). The applied macrophytes were the predominant species of Keszthely Bay (Balaton Lake). Reference (E_o) after Shuttleworth and reference evapotranspiration (ET_o) after Penman-Monteith (FAO-56 formula) were also included for the E study. Of pre-selected four investigated variables, air temperature and air humidity impacted E_p of treated Class A pans the most. Cumulative E_p values for 2016 were 363.1, 427.7, and 461.5 mm in C, S, and P_s , respectively. There was no difference in measured cumulative E_p of P_s (461.5 mm) and computed ET_o (472.1 mm) during the studied season.

On the basis of a simplified water budget, E rate of Keszthely Bay increased with 16.9%, when macrophytes and sediment cover were accounted. It is equivalent to 264,000,000 m³ water in Keszthely Bay's E estimation. Simple E approach - when lake's components, such as submerged macrophytes and sediment cover were also accounted - could extend the accuracy of natural lake's E estimation in a broader circle than earlier.

Key-words: Class A pan evaporation, aquatic macrophytes, Keszthely Bay (Balaton Lake)

1. Introduction

Evaporation (E) is the process of conversion of liquid water to water vapor, widely measured by standard dish filled with water. Evaporation pans provide a measurement of the integrated influence of temperature, humidity, wind speed, and solar radiation on E (Majidi *et al.*, 2015; Kim *et al.*, 2013). In the last century, due to its cost-effectiveness and easy-applicability, pan evaporation (E_p) measuring network has been established worldwide (Stanhill, 2002). The physical basis of Class A pan's E_p was investigated among others by Roderick *et al.* (2007) and Jacobs *et al.* (1998). E_p has also been applied as an index of lake and reservoir E (Wang *et al.*, 2017; Kim *et al.*, 2015; Allen *et al.*, 1998) beyond traditional E_p uses in water budget estimation, plant-weather interactions, etc. Spatial and temporal limitations of pan application due to instrumental and practical issues were also integrated (Martí *et al.*, 2015; Shiri *et al.*, 2011). Several empirical methods based on local variables, in many cases various meteorological drivers, have been developed to estimate E_p in different climate conditions. Weaknesses in use of empirical or half-empirical equations may be the limited data availability and completeness (Majidi *et al.*, 2015). The other option in E estimation is the modeling approach, the Penman-Monteith reference evapotranspiration (ET_0) model (Allen *et al.* 1998, 2005; FAO-56 equation) is probably the most widely employed method among E approximations.

Linacre (1994) issued that E_p does not correspond well to open-water E due to modified intercepted radiation and enhanced heat exchange of the pan wall. To manage issues of A pan's heat transfer modifications, a pan coefficient (below unity) is in use to get near-natural E values (Allen *et al.* 1998; Linacre, 1994). In addition to radiation and heat transfer variations, Rotstayn *et al.* (2006) identified aerodynamic deviations in pan's physical behavior. Recognizing fragility of our knowledge in physical properties of pans, Yang and Yang (2012) found that E pans are not desirable in open-water E estimations. Lim *et al.* (2012) collected the most frequent sources of errors when Class A pan is used: the upper thin layer's surface temperature declines due to evaporation, unknown water mixing inside the dish, experimental shortcomings of some researchers, etc. (Anda *et al.*, 2016).

The term macrophyte comprises plants which are at least with their roots under water (Barrat-Segretain, 1996). One of the three sub-groups of macrophytes (emergent, floating leaved, and submerged) is the submerged one, which keep their leaves permanently under water. Brothers *et al.* (2013) found that submerged macrophytes are the key factors in aquatic ecosystems as they strongly impact lake productivity. Another important role of submerged macrophytes is their contribution to clear-water conditions of shallow lakes and rivers (Hilt *et al.*, 2011). Three predominant submerged macrophyte species are present at Keszthely Bay (Balaton Lake): *Myriophyllum* sp., *Potamogeton* sp., and *Najas* sp. (Vári, 2012).

There are not any studies in the literature that account impact of sediments and submerged macrophytes in estimating lake's E . Information deficit related to living water E approach, when class A pan is in use, might impede for the present measurement of a more accurate E estimation.

2. Materials and methods

2.1. Study site and pan treatments with E estimations

Class A pan's E_p observations were carried out at the Keszthely Agrometeorological Research Station (latitude: $46^\circ 44'$ N, longitude: $17^\circ 14'$ E, elevation: 124 m above sea level) in the growing season of 2016 (Fig. 1). Three different pan treatments were set in the study:

- Class A pan as control pan (C),
- Class A pan implemented with submerged macrophytes (P_s),
- Class A pan with sediment covered bottom (S).

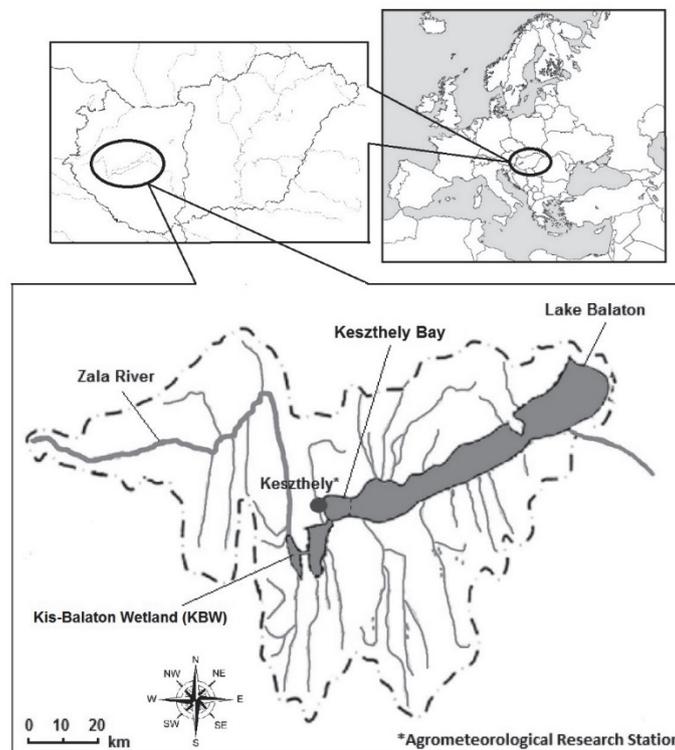


Fig. 1. Watershed of the Balaton Lake with the site of the observation. Meteorological observations with pan evaporation measurements were done at the Agrometeorological Research Station.

Operation of Class A pan, placed on a 0.15 m high wooden platform, was performed following a standard procedure given by the Hungarian Meteorological Service. After daily water height observations carried out at 7.00 am, water replenishing was executed with tap water. Water temperature, T_w at a depth of 0.02 m was measured with thermocouples at 10 min intervals. E_p observations were only carried out during the growing season.

Predominant submerged freshwater macrophytes (*Myriophyllum* sp., *Potamogeton* sp., *Najas* sp.) were implemented into the Class A pan on June 6, 2016, at the same time when the species emerged in the Balaton Lake (Keszthely Bay). The amount and species distribution of plant samples were consistent with plant density of the Keszthely Bay. Fresh weight of samples was determined at the pan's seeding time (spring) and in the end of E measurements, on September 30, 2016. Thickness of sediment on the bottom of Class A pan was 0.02 m. Sediment was obtained from the Balaton Lake. The layout of the pan treatments and instruments of the meteorological station included in the study are presented in Fig. 2.

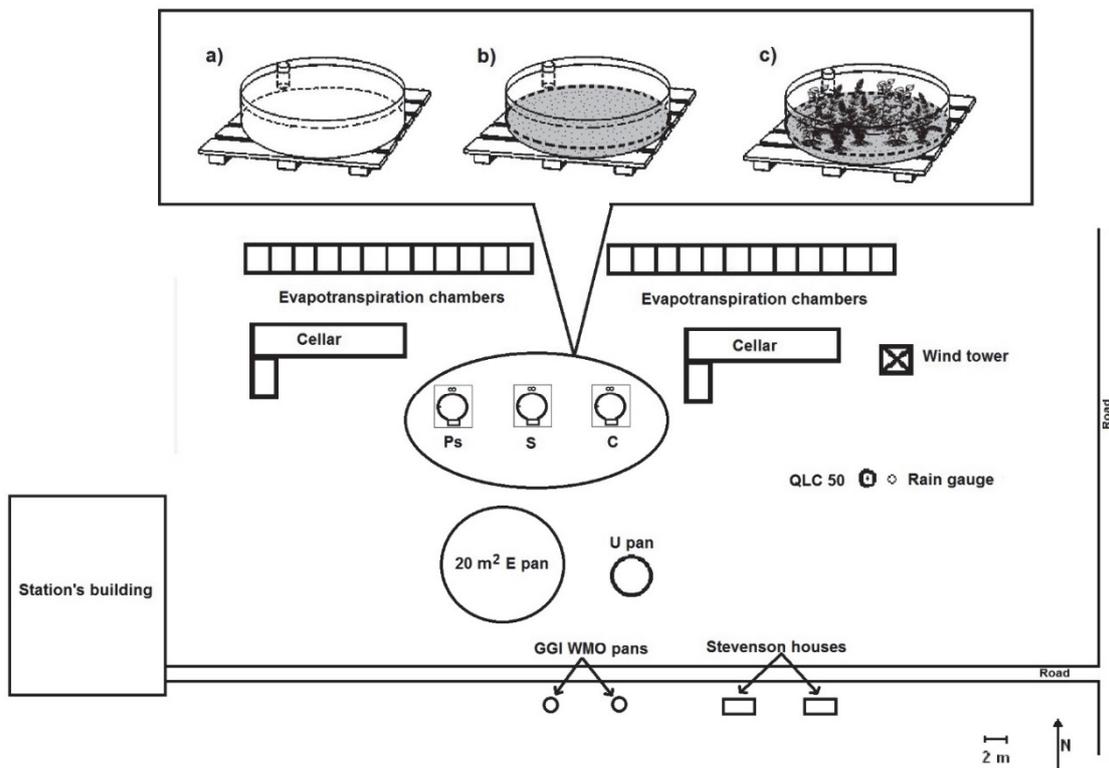


Fig. 2. Layout of the evaporation pans with the sketch of instrumentation of the Agrometeorological Research Station at Keszthely.

Daily E_o rate [mm day⁻¹] of water bodies was computed by the Shuttleworth formula (Shuttleworth, 1993), which was adapted from the original Penman equation (Penman, 1948):

$$E_o = \frac{mR_n + \gamma * 6.43 (1 + 0.536 * u_2) \delta_e}{\lambda_v (m + \gamma)}, \quad (1)$$

where R_n is net radiation [MJ m⁻² day⁻¹], m is the slope of the saturation vapor pressure curve [kPa K⁻¹], u_2 is wind speed [m s⁻¹] at 2 m height, δ_e is the vapor pressure deficit [kPa], λ_v is the latent heat of vaporization [MJ kg⁻¹], and γ is a psychrometric constant [kPa °C⁻¹].

Daily plant ET_o rate [mm day⁻¹] was computed by the widely spread FAO-56 Penman-Monteith equation (Monteith, 1965; Penman, 1948):

$$ET_o = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma \Delta (1 + 0.34 u_2)}, \quad (2)$$

where G is the soil heat flux density [MJ m⁻² day⁻¹], T_a is the mean daily air temperature at 2 m height [°C], e_s is the saturation vapor pressure [kPa], e_a is the actual vapor pressure [kPa], Δ is the slope of the vapor pressure curve [kPa °C⁻¹] and 0.408 is the a conversion factor from MJ m⁻² day⁻¹ to equivalent evaporation in mm day⁻¹. R_n was the estimated using the sediment covered bottom treatment (S), from daily mean T_a , mean daily e_a , the site latitude and elevation after Allen et al. (2005). A fixed value of 0.23 was applied for albedo. R_n was also computed after Allen et al. (2005). Detailed description of the way of R_n computation can be read in Soos and Anda (2014) as follows:

R_n is the difference between the incoming net shortwave (R_{ns}) and the outgoing net longwave radiation (R_{nl}):

$$R_n = R_{ns} - R_{nl}. \quad (3)$$

The net solar or shortwave radiation, R_{ns} [MJ m⁻² day⁻¹] is given by:

$$R_{ns} = (1 - \alpha) R_s, \quad (4)$$

where α is the albedo for the reference crop. The incoming solar radiation, R_s [MJ m⁻² day⁻¹] was measured locally by a CM-3 pyranometer.

Net longwave (outgoing) radiation, R_{nl} [MJ m⁻² day⁻¹] was calculated as follows:

$$R_{nl} = \sigma [T_{mean,K}^4] (0.34 - 0.14 \sqrt{e_a}) (1.35 \frac{R_s}{R_{so}} - 0.35), \quad (5)$$

where σ is the Stefan-Boltzmann constant [$4.903 \cdot 10^{-9} \text{ MJ K}^{-4} \text{ m}^{-2} \text{ day}^{-1}$], $T_{mean,K}$ is the mean temperature during the 24-hour period [K], R_s/R_{so} is the relative shortwave radiation (limited to ≤ 1.0), R_s is the measured solar radiation [$\text{MJ m}^{-2} \text{ day}^{-1}$], R_{so} is the calculated clear-sky radiation [$\text{MJ m}^{-2} \text{ day}^{-1}$].

To get clear-sky solar radiation R_{so} [$\text{MJ m}^{-2} \text{ day}^{-1}$], the station elevation is required:

$$R_{SO} = (0.75 + 2 * 10^{-5}z)R_a , \quad (6)$$

where R_a is the extraterrestrial radiation [$\text{MJ m}^{-2} \text{ day}^{-1}$].

R_a , [$\text{MJ m}^{-2} \text{ day}^{-1}$] is calculated by:

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_s)] , \quad (7)$$

where G_{sc} is the solar constant = $0.0820 \text{ MJ m}^{-2} \text{ min}^{-1}$, d_r is the inverse relative distance between the Earth and Sun, δ is the solar declination [rad], ω_s is the sunset hour angle [rad], φ is the latitude [rad] at Keszthely.

The lacking parametrs are calculated as follows:

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right) . \quad (8)$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right) , \quad (9)$$

where J is the number of the day in the year between 1 (January 1) and 365 or 366 (December 31).

The sunset hour angle, ω_s , is given by:

$$\omega_s = \arccos[-\tan(\varphi) \tan(\delta)] . \quad (10)$$

As the magnitude of the day or ten-day soil heat flux beneath the grass reference surface is relatively small, it may be ignored, and thus (Allen et al., 2005):

$$G_{day} \approx 0 . \quad (11)$$

Class A pan's coefficients (K) were derived from the measured E_p of S (K_s) and P_s (K_p), and the control Class A pan E_p :

$$K_s = \frac{E_p \text{ of } S}{E_p} , \quad (12)$$

$$K_p = \frac{E_p \text{ of } P_s}{E_p} . \quad (13)$$

Weather conditions

Weather variables were recorded by a QLC-50 climate station (Vaisala, Helsinki, Finland) equipped with a CM-3 pyranometer (Kipp & Zonen Corp., Delft, the Netherlands). The combined T_a and humidity sensors were placed at a standard height (2 m above the soil surface). Signals from meteorological elements were collected every 2 second, and 10 minute means were logged by the station. The height of the anemometer was 10.5 m.

The wind speed was adjusted to standard height, u_2 , [m s^{-1}] of 2 m:

$$u_2 = u_z \frac{4.87}{\ln(67.8z_m - 5.42)}, \quad (14)$$

where u_z is the measured wind speed at 10.5 m above the ground surface [m s^{-1}], z_m is the height of measurement above the ground surface (10.5 m).

The weather conditions of the studied months were specified by the monthly Thornthwaite index, TI of the World Meteorological Organisation (WMO, 1975):

$$TI = 1.65(P/T_a + 12.2)^{10/9} \quad (15)$$

where P and T_a are the monthly sum of precipitation and the monthly mean air temperature, respectively.

In classifying the weather conditions in each season's months, a 20% deviation was assumed from the climate normals (1971–2000), above and below the TI_{norm} for both included meteorological variables (P and T_a), allowing the following weather classes to be distinguished (Anda *et al.*, 2014):

- warm-dry month (h): $TI_{month} > TI_{norm} \times 0.8$;
- cool-wet month (c): $TI_{month} > TI_{norm} \times 1.2$;
- month with normal weather (n): $TI_{norm} \times 0.8 \leq TI_{month} \leq TI_{norm} \times 1.2$.

By counting the highest number of months within each of these three groups, the season was considered to be either normal, cool(wet), or warm(dry).

2.2. Statistical analysis

In the analysis of E_p variations with normal distribution [mm season^{-1}] two-tailed t -test was applied. Normality was checked by the Shapiro-Wilks test. When non-normal distribution was observed, a non-parametric statistical hypothesis test, the Wilcoxon signed-rank test was used. To get the influence of meteorological variables (Class A pan, R_n , T_a , T_w , RH , u_z , P) on E_p rates, Pearson's correlation analysis was applied. Analyzing the combined effect of different meteorological variables on E_p rates, multiple stepwise regression analysis was carried out. All tests were carried out with SPSS Statistics version 17.0 software (IBM Corp., New York, USA).

3. Results and discussion

3.1. Weather conditions and dry matter accumulation in the season of 2016

On a seasonal average basis, the mean T_a of Keszthely (16.8 °C) was almost the same as the climate normal (16.9 °C) during the season of 2016. Seasons between 1971 and 2000 are included in the long-term average. Long-term seasonal mean P sum from March through October was 384.4 mm at Keszthely. Conditions in 2016 were much wetter than the long-term average with 525.4 mm P total. Season of 2016 received about one third more rainfall than that of the long-term P sum of the studied region. After all, wet characteristic of our season was also confirmed by the Thornthwaite index classification (*Table 1*).

Table 1. Weather conditions of the studied growing season using the Thornthwaite index, TI

| | April | May | June | July | August | September | i-season |
|-------------|--------------|------------|-------------|-------------|---------------|------------------|-----------------|
| 2016 | dry | wet | normal | wet | wet | dry | <i>wet</i> |

Macrophyte implementation into Class A pan happened with 2.832 kg (fresh weight) of plant mass, on June 6, 2016. Plant material was collected from the lakeshore of Balaton (at Keszthely Bay). Similarly to natural conditions of Keszthely Bay, equal weight of all the three dominant macrophyte species were implemented into Class A pan (*Myriophyllum* sp., *Potamogeton* sp., *Najas* sp.). In the end of the season (September 30, 2016), the harvested fresh weight of submerged aquatic macrophytes was almost twice as much as the initial weight (4.763 kg).

3.2. E_p , E_o , and ET_o variations during 2016

E_p of C ranged from 0.7 to 5.8 mm day⁻¹ on July 12 with a seasonal average of 3.03±1.23 (*Fig. 3*). E_p of S ranged from 0.7 to 6.9 mm day⁻¹ on July 5 with a seasonal average of 3.65±1.51. In the pan with macrophytes, E_p ranged from 1 to 7.3 mm day⁻¹ on August 6 with a seasonal average of 3.84±1.57. Reference E_o and ET_o values exceeded the measured E_p ones. Daily mean E_o and ET_o were 4.65±1.43 and 3.93±1.25, respectively. The maximum E_o and ET_o values occurred on June 25 and 28 as 7.2 mm day⁻¹ and 6.1 mm day⁻¹, respectively. The probably reason of low pan E_p might has been the special geographical position of

Keszthely meteorological station. The meteorological station is placed at about 200 m from Keszthely Bay (Balaton Lake), that is sheltered by surrounded mountains causing lower wind speeds (*Anda et al.*, 2016). In accordance with the studies of *McVicar et al.* (2012), there has also been a decline in near surface u , contributing to a reduced rate of evaporative demand.

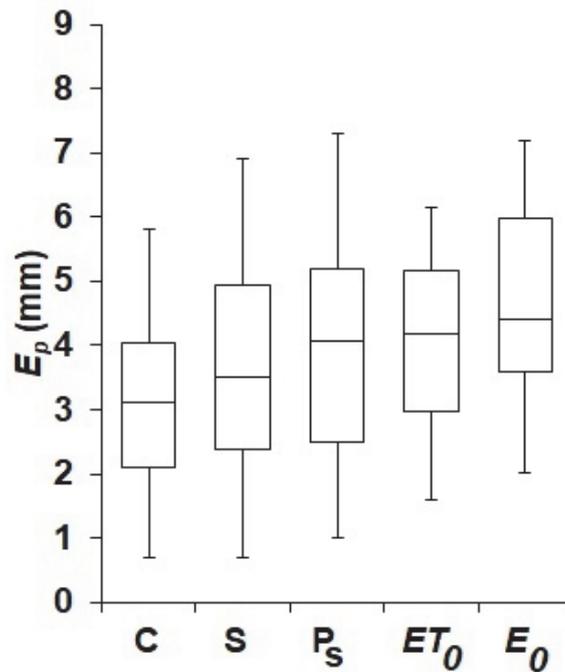


Fig. 3. Statistical analysis for daily Class A pan evaporation, E_p during the 2016 growing season. The bottom and top of boxes are the 25th and 75th percentiles (the lower and upper quartiles), respectively, and the band near the middle of the boxes is the median (50th percentile). Vertical lines that end in a horizontal stroke above and below each box are drawn from the upper and lower hinges to the upper and lower adjacent values. C, S, and P_s denote Class A pan, Class A pan with sediment-covered bottom, and Class A pan implemented with macrophytes, respectively.

Both sediment cover and macrophytes placed Class A pan increased daily E_p rates significantly. Increments in seasonal mean daily E_p rates were 16.3% ($p \leq 0.0001$) and 23.8% ($p \leq 0.0001$) in S and P_s , respectively. Difference in measured daily mean E_p and computed E_0 was even greater (42.3%; $p \leq 0.0001$). No deviation between ET_0 and E_p of P_s ($p \leq 0.2838$) was observed, confirming that Class A pan E_p implemented with submerged macrophytes is closer to the computed reference ET_0 than that of the empty Class A pan. Surprising result emerged when E_0 and ET_0 were compared; a 16.6% ($P \leq 0.0001$) overestimation was found with E_0 in comparison to ET_0 .

According to daily mean E_p rates, the cumulative E_p values were 363.1, 427.7, and 461.5 mm in C, S, and Ps, respectively (Fig. 4). At the same time, higher reference E values were computed (E_o : 551.9 mm; ET_o : 472.1 mm). The impact of pan implementation for total E_p was always highly significant ($p \leq 0.0001$). There was no difference in the measured cumulative E_p of Ps (461.5 mm) and computed Penman-Monteith ET_o (472.1 mm) during the season of 2016 ($p \leq 0.2400$).

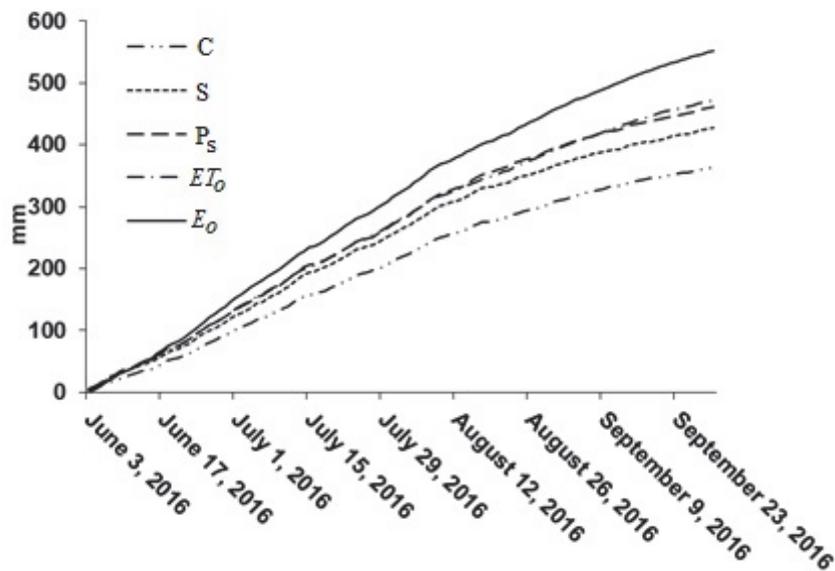


Fig. 4. Cumulative evaporations [mm] of Class A pan, implemented pan with macrophytes (P_s), and implemented pan with sediment cover (S), and the reference evaporation, E_o . ET_o denotes the Penman-Monteith reference evapotranspiration total.

Irrespective of pan treatments, there was a large scatter in the data of daily measured E_p rates and computed reference E_o values (Fig. 5).

The slopes of linear regression between measured and computed E rates ranged from 0.68 to 0.92 (RMSE: 0.0679 – 0.7007 mm day⁻¹). Better fit was observed between E_o and E_p with implemented macrophytes (slope: 0.92). Irrespective of pan treatments, computed E_o rates overestimated the measured E_p values during the 2016 growing season.

The relationship between the measured E_p of implemented Class A pan and reference ET_o (using Suttleworth formula) is improved in comparison to the relation between E_p and E_o (Fig. 6).

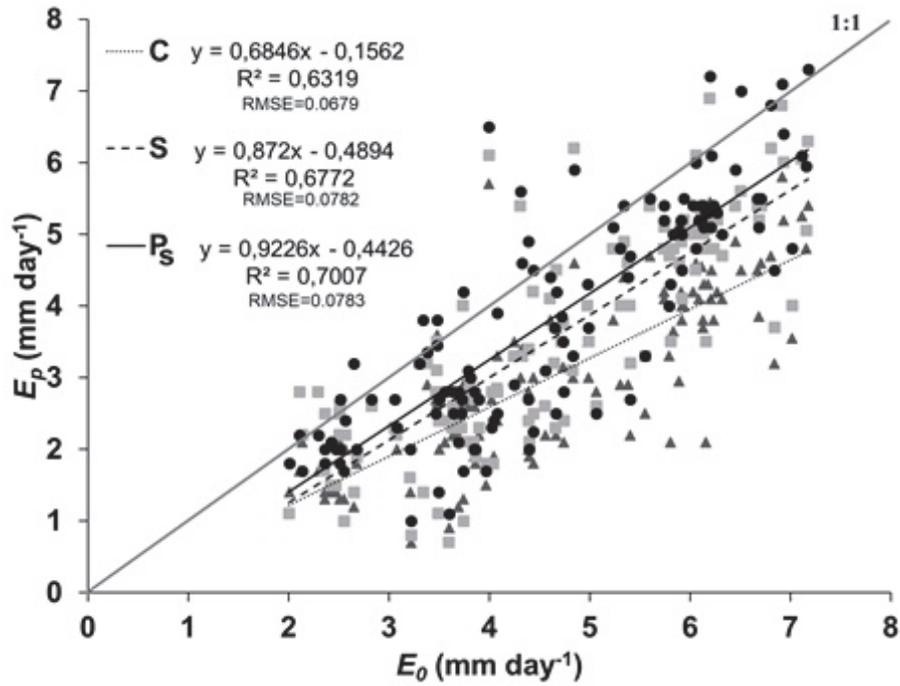


Fig. 5. Relationship between the daily measured Class A pan evaporations (E_p) and daily reference evaporations (E_o) computed by the Suttleworth formula. C, S, and P_s denotes empty, sediment covered, and macrophyte implemented Class A pans, respectively.

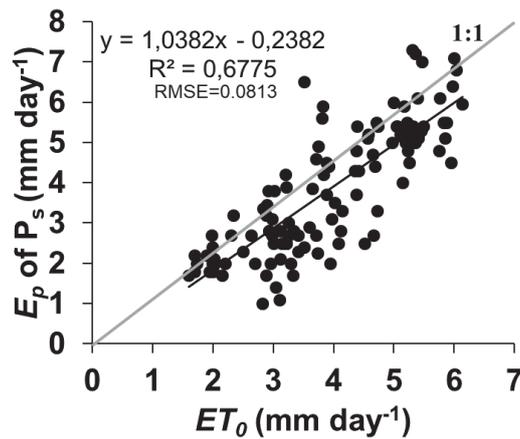


Fig. 6. Relationship between the daily measured pan evaporation (E_p) of Class A pan implemented with macrophytes and daily reference evapotranspiration (ET_o) computed by Penman-Monteith (FAO-56) formula.

The slope of linear regression was close to 1 (1.03; RMSE: 0.0813 mm day⁻¹) implying that Penman-Monteith approximation (reference ET_o) seems to be useful in estimation of the vaporation of the lake that contains submerged aquatic macrophytes.

3.3. Pan coefficient, K for implemented Class A pans

The ratio between the implemented Class A pan's E_p and empty pan's E_p provided a pan coefficient for those pan containing sediments (K_s) and/or macrophytes (K_p). The way of obtaining these coefficients was similar to computing the widely applied crop coefficients (K_c) in evapotranspiration estimation. In accordance to increased daily and total E_p values for implemented Class A pans, the monthly average K values permanently exceeded 1 (Table 2). The seasonal mean K_s and K_p values were 1.18 (range: 1.13–1.27) and 1.30 (range: 1.24–1.37) in S and Ps, respectively. The highest increments in K values were observed during June, due to warmer weather conditions.

These K values may be useful in improving the Class A pan based E estimation of lakes or reservoirs which contain sediment covered bottom and/or submerged macrophytes.

Table 2. Monthly average pan coefficients for Class A pan with sediment-covered bottom (K_s) and containing macrophytes (K_p) in the growing season of 2016

| | 2016 | | | | |
|-------|-----------|-----------|-----------|-----------|------------------|
| | June | July | August | September | Mean |
| K_s | 1.27±0.24 | 1.19±0.15 | 1.14±0.15 | 1.13±0.3 | 1.18±0.22 |
| K_p | 1.37±0.29 | 1.24±0.23 | 1.33±0.41 | 1.26±0.15 | 1.30±0.29 |

3.4. Impact of weather on E_p of implemented Class A pans

Correlation analysis to study the influence of weather variables (daily mean of T_a ; daily means of water temperature, T_w ; net radiation, R_n ; relative humidity, RH ; wind speed u ; precipitation P) on daily measured E_p rate of Class A pan with macrophytes and/or sediment cover was carried out (Table 3).

Table 3. Correlation coefficients (r) for daily measured evaporation rate (E_p) for Class A pans with macrophytes and/or sediment cover. The following daily weather variables were accounted: daily mean of air temperatures, T_a ; daily means of water temperature, T_w ; net radiation, R_n ; relative humidity, RH ; wind speed, u_z ; and precipitation, P

| | Class A pan [mm] | R_n [MJm ⁻²] | T_a [°C] | T_w [°C] | RH [%] | u_z [ms ⁻¹] | P [mm] |
|----|------------------|----------------------------|------------|------------|-----------|---------------------------|----------|
| S | 0.941** | 0.789*** | 0.560*** | 0.577*** | -0.571*** | 0.075 | 0.144 |
| Ps | 0.913*** | 0.795*** | 0.590*** | 0.642*** | -0.577*** | 0.076 | 0.126 |

* Marginally significant correlation $|r|>0.1$, $p<0.01$

** Marginally significant correlation $|r|>0.1$, $p<0.001$

*** Significant correlation $|r|>0.4$, $p<0.0001$

The closest relationship between the E_p of Class A pan and E_p of S ($r=0.941$) and Ps ($r=0.913$) was not unexpected. Meteorological variables related to available energy (R_n , T_a , T_w) have also high positive correlation coefficients in both implemented pan treatments (S and Ps). R_n had governmental role in E_p regulation on the basis of its correlation coefficient size among energy related variables ($r=0.789$ and $r=0.795$ in S and Ps). Somewhat lower correlation coefficients of T_a and T_w ranged from $r=0.56$ (S) to $r=0.642$ (Ps). *Martinez et al.* (2006) and *McVicar et al.* (2007) communicated the decisive effect of T_w on the rate of Class A pan E_p . *Gundalia and Mrugen* (2013) and *Xiaomang et al.* (2011) also found high positive correlation between T_a and E_p . In our study, a negative correlation of $r=-0.57$ was noticed with RH (both E_p of S and Ps), in accordance with earlier observations of *Singh et al.*, (1992).

A weak positive correlation coefficient for u has not confirmed the earlier result of *McVicar et al.* (2012) for E_p . The probably reason of very loose relation between u and E_p may be the geographical position of Keszthely Bay, that is sheltered by Keszthely Mountains from the side of prevailing northern wind direction. Weak correlation of P with E_p came as no surprise, due to the water replacement practice of pan operation.

E_p rate is defined as the difference in vapor pressure between the pan's surface and surrounding atmosphere, providing a simple integrated measurement of complex meteorological interaction between R_n , T_a , RH , u_z , and E_p (*Roderick et al.*, 2009). Due to strong variability in the magnitude of the above specified meteorological elements, measured E_p rates can strongly differ from place to place (*Yang and Yang*, 2012). These qualifying differences in spatial E_p might also be displayed in variation of correlation coefficients existing between meteorological variables and E_p rates.

Only easily accessible meteorological variables are included in the multiple stepwise regression analysis (T_a , RH , u_z , P). Class A pan, R_n and T_w were excluded

from the investigation. In the course, three meteorological variables remained in the regression equations (T_a , u_z , and RH). These meteorological variables are available even in such places where meteorological stations are missing (research stations, universities, etc.). Our analysis showed that two meteorological variables (T_a and RH) impacted the E_p of P_s and S the most (Table 4). The first two equations of Table 4 present the possibility of computing E of a lake/reservoir with macrophytes and/or sediments, when the only available meteorological variable is the T_a (in P_s) or RH (in S). The second two equations of E , estimation when macrophytes and sediment cover are accounted, contain two meteorological variables, T_a and RH . Observation of T_a or RH might not cause difficulties in the present time.

Table 4. Multiple stepwise regression analysis between meteorological elements (air temperature, T_a ; relative humidity, RH ; wind speed u_z , precipitation, P) and measured Class A pan evaporation (E_p) with macrophytes (P_s) and sediment covered bottom (S) in the season of 2016. r : coefficient of multiple correlation.

| | Adjusted r^2 | F | F sig. | SE of coefficient | Regression equation |
|-------------------|----------------|--------|----------|---------------------|----------------------------------|
| 1. E_p of S | 0.321 | 57.227 | 0.000 | Const.= 1.385 | $E_p = -0.139RH+14.003$ |
| | | | | $RH = 0.018$ | |
| 2. E_p of S | 0.497 | 59.776 | 0.000 | Const.= 1.540 | $E_p = -0.111 RH+0.212T_a+7.660$ |
| | | | | $RH = 0.016$ | |
| | | | | $T_a = 0.033$ | |
| 1. E_p of P_s | 0.343 | 63.059 | 0.000 | Const.= 0.752 | $E_p = 0.297T_a-2.051$ |
| | | | | $T_a = 0.037$ | |
| 2. E_p of P_s | 0.530 | 68.201 | 0.000 | Const.= 1.548 | $E_p = 0.237T_a-0.114RH+7.740$ |
| | | | | $T_a = 0.033$ | |
| | | | | $RH = 0.016$ | |

3.5. Simple water budget terms on Balaton Lake (Keszthely Bay) during the growing season of 2016

There are two important terms describing the simplified water budget of a lake: the precipitation P as an input and the evaporation E as the output of water. Specification of exact water balance of studied site was excluded from our investigation. Our purpose was a simple comparison of the two most important simplified water balance members at Keszthely Bay. The area of Keszthely Bay is 39 km², less than 10% of the whole area of Balaton Lake. Based on local observations, the submerged macrophytes occupies 5–10% of the whole bay (Anda et al., 2016). The remaining part of the bay accounted for as covered bottom with sediments.

Despite wet conditions of the growing season, computed E of Keszthely Bay surpassed seasonal amount of P in 2016 (Table 5). Slightly more than 90% of E derived from P in the 2016 growing season. On daily mean basis, the E rate of Keszthely Bay increased with 16.9% when macrophytes and sediment cover were accounted. Increment in seasonal total E for the whole bay resulted 264,000,000 m³ water, when macrophytes and sediment cover were included in Keszthely Bay's E estimation. During arid seasons, this E rate may increase substantially strengthening the importance of E related investigations of natural lakes.

Table 5. Seasonal sums of precipitation (P) and evaporation (E) [mm] of Keszthely Bay including daily E rates [mm day⁻¹]. The E estimates of the lake were based on weighting averages of a) using pan coefficients with sediment-covered bottom (K_s), and macrophytes (K_p) and b) simple Class A pan measurements.

a) Simple water budget terms of Keszthely Bay (macrophytes and sediment cover included)

| Seasonal sums [mm] | | Daily rates [mm day ⁻¹] | | Water total [10 ⁶ m ³] | | |
|-----------------------|--------|--|------|--|------|----------|
| P | E | Δ | E | P | E | Δ |
| 328.5 | 430.69 | -102.19 | 3.59 | 12.81 | 16.8 | -3.99 |

b) Simple water budget computed by Class A pan data only

| Seasonal sums [mm] | | Daily rates [mm day ⁻¹] | | Water total [10 ⁶ m ³] | | |
|-----------------------|--------|--|-------|--|-------|----------|
| P | E_p | Δ | E_p | P | E_p | Δ |
| 328.5 | 363.15 | -34.65 | 3.03 | 12.81 | 14.16 | -1.35 |

4. Conclusions

A simple approach was presented to evaluate the E of a natural fresh water lake in Hungary. To achieve this goal, Class A pans were implemented with aquatic submerged macrophytes and/or their bottom was covered by sediment. E_p rate of treated Class A pans increased significantly. The impact of macrophytes and sediment cover on the E of the lake can be computed directly through using pan's coefficients.

In our study, we received a Class A pan coefficient of above 1 (K_{as} :1.18; K_{ap} :1.3) in comparison to the calculated potential evapotranspiration, which is in contrast to the most reported cases in the literature, where values of well below 1 (around 0.75) were received. Similarly to our outstanding results in 2016, annual

mean value of 0.99 for one separate warm and arid year was published by *Sabziparvar et al.* (2009). *Allen et al.* (1998) have also imparted that Class A pan coefficient may vary highly depending on the geographical site and the actual weather conditions.

The reason of K_c deviation could lie in biased wind profile – i.e., biased measurement of wind speed and/or its correction to 2 m height. Moreover, the special hill-surrounded (shadowed) location of Keszthely Agrometeorological Research Station may also reduce the impact of wind on evaporation. *Roderick et al.* (2007) revealed differences among 41 investigated sites between 1977 and 2004, where decreasing wind speed was found to be the main reason for changing Class A pan evaporation. Other possible reason of altered K_c may be the estimation of net radiation instead of measurement together with neglected factors influencing pan energy balance. Therefore, our Class A pan coefficient should be used with attention to local environmental conditions, and should be re-calibrated before application, if possible.

Growing season of investigation has the characteristic of a wet weather. Even in the course of the wet season, the increment in E of Keszthely Bay (Balaton Lake) reached 16.9% (264,000,000 m³), when macrophytes and sediments were also accounted. This simple approach using pan coefficients may extend the accuracy of the E estimation of natural lakes, based on Class A pan in a broader circle than earlier.

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