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Analyzing long-term evapotranspiration of Lake Fenéki wetland (Kis-Balaton, Hungary) between 1970 and 2012

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Abstract—The aim of the study was to estimate long term evapotranspiration (ET) of Kis-Balaton wetland through the investigation of Lake Fenéki. Data set was processed using the West-transdanubian Water Inspectorate methodology. Potential evapotranspiration (PET) was calculated using Hungarian empirical models (*Antal* and *Dunay*), while Lake Fertő formula was applied evaluating the ET that includes the impacts of vegetation.

Calculated PET values of the wider (adjacent) environment of Lake Fenéki (Zalaegerszeg, Nagykanizsa, and Keszthely meteorological stations) differed significantly and further variation was observed in PET, when measured meteorological elements on Lake Fenéki were applied. PET increment, as a result of linear trend fitted to the 43-year long data (Keszthely station) was 3–4 mm year^{-1}. Relation between PET calculated from the data of Keszthely station and for Lake Fenéki was strong, so PET of Lake Fenéki can be originated from the data of Keszthely station. Calculated ET was not significantly different due to the likely similar input data in ET calculation model of Hungarian Meteorological Service (OMSZ).

43-year annual mean ET for Lake Fenéki was 809±88 mm. This ET was 84% of calculated PET. Analyzing the nine dry-warm seasons, average annual ET exceeded the long term average (874.7±37.6 mm) with 78 mm. The average ET of the remaining 34 wet-cold seasons totalled 796.6±89.4 mm.

Empirical formulas cannot be replaced, according to monthly ET comparisons, by using “A” class pan estimating the ET of aquatic habitats.

Seasonal pattern of monthly ET time series for Lake Fenéki was analyzed using autoregressive integrated moving averages (ARIMA) modeling technique. After first differencing, the transformed series was stationary and found to be governed by moving average process of order 1.

Key-words: wetland evaporation, potential evapotranspiration, seasonal ARIMA, Kis-Balaton wetland (Lake Fenéki)

1. Introduction

Kis-Balaton is a large, continuous wetland. It used to belong to Lake Balaton (Western bay). In 1863, suitable circumstances turned up to control the water level more or less separately from meteorological conditions (*Harkay*, 1983; *Virág*, 1997). Prior to the opening of the Sió-sluice in 1863, the water level of Lake Balaton was determined by the prevailing weather conditions. When the sluice gate of Channel Sió was built, the natural fluctuation of water level decreased to 0.5 m or less (earlier the fluctuation of water level could be as high as 3–5 meters). In the first part of the 19th century, the water level of Lake Balaton was lowered in several steps, therefore, the higher areas of the Kis-Balaton basin dried out. The water level turned to 2–3 m lower than the water level of the ancient lake (*Kovács et al*., 2010; *Hatvani et al.,* 2011). The surface of Kis-Balaton wetland became smaller, water cover of higher parts disappeared, and it appeared again when River Zala flooded. In the 1920's banks were built to both sides of River Zala. As a consequence of the regulation, the Kis-Balaton and other surrounding marshes lost their function to protect the water quality of Lake Balaton. It was strengthened by the consequences of civilization, i.e., intensive agricultural chemicalization, increasing urbanization, developing and spreading of holiday resorts in the region, which altogether resulted in the significant deterioration of quality of waters entering Lake Balaton. This marsh supplied an ideal habitat for plants and animals preferring aquatic habitats. As the area became drier, the surface of the marsh got smaller (*Nguyen et al.,* 2005). At the deepest part – close to Island Diás –, two small lakes and the surrounding reed (about 1400 ha) remained behind. This area is under strict protection according to *Ramsar Convention* (1971). Because of the regulation works, the water protecting function of Kis-Balaton and the ambient groves ended.

In the 1960–70's, especially in Keszthely Basin, water quality of Lake Balaton notably decayed (*Istvánovics et al,*. 1997; *Padisak* and *Reynolds*, 2003), so a resolve was made about the artificial reconstruction of the marsh (Kis-Balaton Water Protection System, KBWPS) and the restitution of the water protecting function of Kis-Balaton (*Pomogyi et al.,* 1996; *Tátrai et al.,* 2000). Construction works began in 1981, the Stage 1, called Lake Hídvég, was constructed between 1981 and 1985 (*Korponai et al.,* 2010).

Due to economic reasons, the construction did not follow the planned timing, so in behalf of water quality of Lake Balaton a makeshift was made. In 1992, the north-northwest part of Lake Fenéki was flooded. The area was called Grove Ingói (16 km^2).

Constructions were made at the non-flooded area of Lake Fenéki as well (outer reservoir). The water of Zala-Somogy border ditch and the Marótvölgyi Channel was led to this area. One part of the effluent water from Lake Hídvégi – mostly in case of fill of water – was directed to the non-flooded area. This caused a temporary flood and reservation. Complete construction of the Kis-Balaton Water Protection System Stage 2 is still in process (Project KEOP 2.2.1/2F/09-2009-0001). In 2015, the flood of outer reservoir is expected to happen. Coordination of water quality protection, conservation, flood and water conservation objectives and tasks is going to occur in the project.

In case of flow-through lakes (like Kis-Balaton), inflow and outflow are the most important members of the water balance. In Lake Fenéki, this value can be as high as 90% on annual basis. Although the share of evaporation is usually just under 10%, accurate estimation of evapotranspiration (*ET*) is important, because during summer – in the lack of notable flood – it can reach 30–70% of inflow and outflow. Typically, in case of low water conditions, it is problematic prescribing the water balance.

Evaporation is a major energy-consuming physical phenomenon, which can be significantly affected by climate change (*Novaky*, 2005). To refine the hydrological and climatic forecasts, it is necessary to estimate evaporation irrespectively of the other members of water balance equation.

There are only a very few studies which determine *ET* in the area of Kis-Balaton. Hungarian researchers have investigated only the *ET* of bigger lakes (*Havalda,* 1930; *Szesztay*, 1962; *Antal,* 1968; *Antal et al.,* 1977; *Varga,* 2005; *Varga et al.,* 2007).

This research aims to overview the practice of *ET* calculation used by the Inspectorate for Water Management for decades, and to produce a long time series *ET* dataset for Lake Fenéki. Time series is a collection of quantitatively measured data evenly spaced in time. Analysis of the time series is important to understand the structure and functioning of observed data. Time series analysis allows a mathematical model to be built in order to discuss the data trend (*Box et al.,* 2008; *Brockwell* and *Davis*, 2001; *Psilovikos* and *Elhag*, 2013). The autocorrelation elements of the data were extracted using ARIMA to model the underlying wetland evaporation trend more precisely.

2. Materials and methods

Our study aimed ET of Lake Fenéki (46°38’N, 17°11’E, altitude 194 m, area 54–57 km^2), which is situated in the natural valley of River Zala between Balatonhídvég and the mouth of Zala, and it is the planned reservoir of the Kis-Balaton Water Protection System Stage 2. On the northern part of the reservoir, water is kept by the southern watertight dam, on the western part by the Zalavár dam. On the east side, Zala valley is closed 3.5 km wide by the valley occlusion parallel with the railway line (*Fig. 1*).

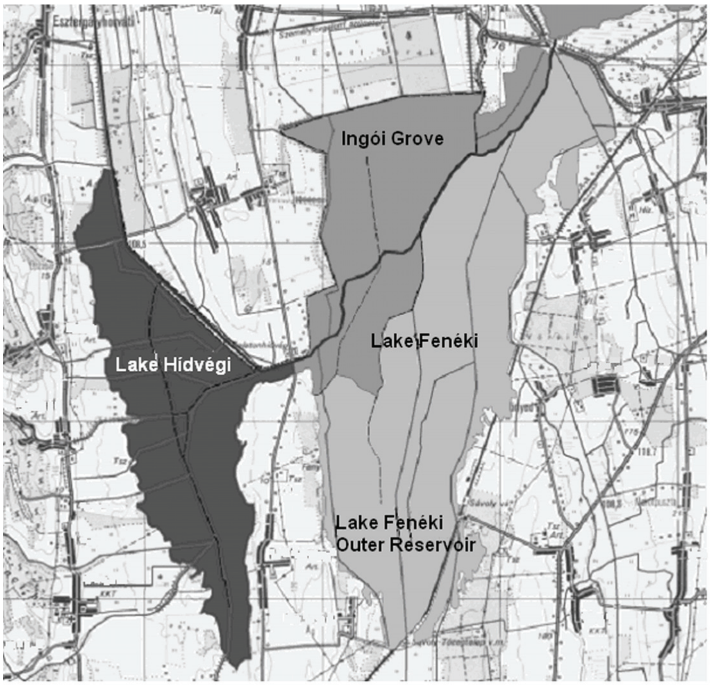

Fig. 1. The Kis-Balaton wetland including the site of the study, the Lake Fenéki (Fenéki Outer Reservoir and Grove Ingói).

When KBWPS was created, quantitative recording of its water budget has also begun with the traditional water balance equation, which includes the basic characteristics of water movements (*Zsuffa,* 1996). Members of the equation were determined from 1986 for Lake Hídvégi. In the case of Lake Fenéki, first calculations were made only after constructions have been completed, measuring points were installed, and the northwest part was flooded. Monthly water balance calculations for Grove Ingói and Lake Fenéki Outer Reservoir had started since 1993 and 2003, respectively. On the input side, the natural inflow (*H*), the precipitation (*C*), and the amount of water pumped (*SZ*) were taken into account, while on the output side, the outlet (*L*) and *ET* were listed. The change in water resources (*ΔK*) was calculated from the increase or decrease of the water level using the volume curve edited by the West-transdanubian Water Inspectorate. Subsurface water movements (inflow, leakage) are usually not quantified due to its negligible extent.

Water balance for Kis-Balaton (in the case of the three parts: Lake Hídvégi, Grove Ingói, and Lake Fenéki Outer Resevoir) is calculated separately in the following form:

$$(C + H + SZ) - (ET + L) \pm \Delta K = 0. \tag{1}$$

In the present study, our aim was to determine the evaporation of Lake Fenéki (Grove Ingói + Lake Fenéki Outer Reservoir). Methods for calculating

ET for Hungarian areas are presented in numerous studies (*Tölgyesi*, 1993; *Kontur et al.,* 1993). When choosing a method, it is an important aspect, that data should be available from the regional meteorological parameters. The investigated period is 1970–2012, 43 years altogether. From the beginning of this period, meteorological measurements in the area of Kis-Balaton were made only at the stations in Zalaegerszeg, Keszthely, and Nagykanizsa. From these observations, air temperature and humidity data were available from 1970.

Wind speed and global radiation were available from the latter time. The West-transdanubian Water Inspectorate established automatic hydro-meteorological stations (Balatonmagyaród Fekete Island, Balatonmagyaród beach 4T, Balatonmagyaród Almás Island, Keszthely-Fenékpuszta 21T) from the end of the 1990's. Air temperature, relative humidity, wind speed, and solar radiation were measured there. The data of the evaporation pan ("A" pan) at Balatonmagyaród beach 4T station are continuous from 1998.

The used data were as follows:

- Zalaegerszeg, Nagykanizsa (1986–1995): monthly potential evapotranspiration (*PET*) and *ET* based on the calculations of OMSZ (Hungarian Meteorological Service) (see later);
- Keszthely: monthly *PET* and ET (1970–1996; 2002–2012) on the basis of the OMSZ dataset;
- Keszthely: daily average temperature, relative humidity (1970–2012);
- Balatonmagyaród beach 4T, Balatonmagyaród Almás Island, Keszthely-Fenékpuszta 21T: daily average temperature, relative humidity, average wind speed (1993–2012).

Evaporation values (*PET, ET*) calculated by the operational soil moisture model (*Dunay,* 1993) developed for agrometeorological purposes was applied in this study. Data were taken from related OMSZ publications.

The long record of PET was approached in two ways. The Antal-formula which was developed for potential evapotranspiration in Hungarian climate conditions (*Antal*, 1968) was approached with the meteorological data of Keszthely for the whole period:

$$PET = 0.9(E-e)^{0.7}(1+\alpha t)^{4.8}\, n \quad [mm / month], \tag{2}$$

where E is the saturation vapor pressure [hPa], e is the vapor pressure [hPa], α=1/273, t is the average air temperature [°C], and n is the number of the days in the month.

Monthly evaporation values were summarized annually. In the other method (earlier referenced as operational soil moisture model), data were taken from OMSZ agrometeorological publications for 1970–1996 on monthly basis. Data of 2002-2012 were summed from decade calculations for the water sector. For supplying the missing monthly data, we used linear regression using the monthly values of the Antal-formula. Correlation before the supplement was 0.972.

For calculating *ET* at Kis-Balaton instead of developing a new "Kis-Balaton formula", which fits the local conditions, experts suggested using the Antal-formula for the determination of evaporation loss, although it was developed for Lake Fertő. The reason was that reed cover of both lakes was extensive. For water balance calculations, monthly *ET* was determined using the Lake Fertő formula for Grove Ingói as well:

$$ET = 0.42(E-e)^{0.9}(1+\alpha t)^{9}(1+0.015 \cdot u)^{2} n \quad [mm/month], \tag{3}$$

where u is the monthly average wind speed [m/s]. To create this equation, energy balance measurements were made.

Evaporation increasing effect of wetland vegetation was taken into account with correction factors (crop coefficient) from April to October according to *Table 1*.

Table 1. Monthly average of crop coefficients for Kis-Balaton wetland

	Apr	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Crop coefficients	1.02	1.11	1.2	1.26	1.21	1.13	1.11

For determination of local evaporation at Lake Fenéki Outer Reservoir, the method developed by *Dunay et al.* (1968) was used, which is based on "A" pan measurements:

$$ET = (100 - H_{\%})(200 - H_{\%})^{-1} \cdot t \cdot n \quad [mm/month], \tag{4}$$

where $H_{\%}$ is the monthly mean of relative humidity (%).

In hydrological practice, the water balance equation equals to 0, as the sum of positive and negative amounts. The expert calculating the equation needs a lot of data as many times as estimations are required. Flow rate of bigger streams is measured, some of them in every 15 minutes, but weekly or monthly measures are more common. At the most segments, water level series is created measuring the water level frequently, which is transformed into runoff time series. Integrating this series in time allows calculating the amount of inflow. Smaller streams are estimated based on hydrological analogy. At the outflow of Lake Fenéki (into Lake Balaton), some problems can temporarily occur because off the strong upwind. In this case, an inverse circulation shows up at the surface and a kind of pulse is registered while measuring runoff. This phenomenon can be caused by the seiche of Lake Balaton. The quantification and determination of its effect on the amount of runoff should be solved in the future. In the case of precipitation over the lake, data of some precipitation gauges are considered. The precipitation of the 75 km^2 surface is calculated from the data of 3–6×200 cm^2 surfaces. Neither the surface nor the volume curves are renewed, although at some parts of Lake Hídvégi, sedimentation has begun. Curves of Lake Fenéki are sensitive; they change significantly in the error limit of water level registration. Accurate inventory of evaporation loss is not resolved, estimations containing error use of crop coefficients makes the review of vegetation rough. All of these can lead to significant errors. Experience has shown that water balance calculations are more difficult in the case of lower water level.

In a time series, within a normal data distribution, a two-tailed t-test was applied. To compare differences, when the Shapiro-Wilk normality test indicated a non-normal distribution, a non-parametric statistical hypothesis test, the Wilcoxon signed-rank test was used (SPSS Statistics v. 17.0; IBM Corp., New York, USA). To compare between daily *PET*s calculated on locally measured data observations at Keszthely, a linear regression ($y = a + bx$) was carried out, in which local *PET* was used as the dependent variable y and *PET* of Keszthely was the independent variable x. The fitness of curve was acceptable when the slope forced through the origin of the regression was close to 1 (*Alexandris* and *Kerkides*, 2003).

The purpose of the study was to develop ET prediction for Lake Fenéki. Originally the Box-Jenkins models were used for time-series analysis (*Box* and J*enkins*, 1976) in the form of a seasonal auto-regressive integrated moving average (ARIMA(p,d,q)$(P,D,Q)_s$) model.

Box and *Jenkins* (1976) recommended the following general model:

$$\phi_p(B)\Phi_P(B)(1-B)^d\left(1-B^s\right)^D X_t = \theta_q(B)\Theta_Q\left(B^s\right)\alpha_t, \tag{5}$$

where d is the order of differencing, s is the length of the season, and D is the order of seasonal differencing.

The operator polynomials are as follows:

$$\phi_p(B) = \left(1-\phi_1 B - \ldots - \phi_p B^p\right), \tag{6}$$

$$\theta_q(B) = \left(1-\theta_1 B - \ldots - \theta_q B^q\right), \tag{7}$$

$$\Phi_p\left(B^s\right) = \left(1-\Phi_1 B^s - \ldots - \Phi_p B^{sp}\right), \tag{8}$$

$$\Theta_Q\left(B^s\right) = \left(1-\Theta_1 B^s - \ldots - \Theta_Q B^{sQ}\right), \tag{9}$$

$$\left(1-B^{s}\right)X_{t}=X_{t}-X_{t-s}\,. \tag{10}$$

Among others, *Meshram et al.* (2011) applied seasonal ARIMA model to project evaporation for India (Solapur Station). The original *ET* time series for Lake Fenéki has not demonstrated any trend; data exhibited numerous peaks, which appeared to be equally spaced. This phenomenon suggested the presence of a periodic component to the time series, where the peak took place in the growing seasons.

To determine ARIMA model for time series analysis and produce forecasts, the SPSS 17.0 statistical program was applied. The program includes an expert modeler modul that automatically estimates the best-fitting ARIMA model, eliminating the need to identify an appropriate model through trial and error.

There are three basic terms of ARIMA models; auto-regression (AR), differencing or integration (I) and moving-average (MA) components. Although these components respond differently to a random disturbance, they are based on the concept that they may be described by ARIMA models. Since time series showed seasonality, the seasonal ARIMA (p,d,q)(P,D,Q)$_s$ orders were presented. An effective approach for isolating seasonal orders is to calculate the autocorrelation functions (ACF) and partial autocorrelation function (PACF) plots at the seasonal lags (http://www.spss.com). The number of spikes showed the order of auto-regression.

3. Results and discussion

The Kis-Balaton lake system, in which Lake Hídvégi is about 18 km^2, is typically an open water area (85%). The cover of marsh vegetation is about 15%. The area of Grove Ingói is about 16 km^2. The distribution of open water, reed, bulrush, and sedge shows a mosaic structure. Here, the share of open water is only about 15%. The Lake Fenéki Outer Reservoir – the non-flooded area – is about 41 km^2. The permanent water cover is low, about 1–2%, but temporarily it can be higher (even almost the whole area), belonging to the shallow water covered, wetland types.

A ten-year period was chosen to overview the evaporation conditions of the wider environment, which includes our study site as well. The calculated monthly values of *PET* and *ET* between 1986 and 1995 at the three sites near Lake Balaton (Keszthely, Zalaegerszeg, Nagykanizsa) matched only in respect of *ET*. *PET* values of the three stations differed significantly ($p \leq 0.0001$). The annual sums ranged between 840 and 1120 mm. The average of the ten years is the highest in Kesztely (1060 mm) as expected. This is followed by Zalaegerszeg (1025 mm) and Nagykanizsa (940 mm). Monthly maximum of *PET* occurred in August 1992 (245 mm) in Keszthely. The maximum of *ET* (144 mm) calculated by the OMSZ operational soil moisture model occurred in July 1991, the annual sums are between 460 and 760 mm, but the differences are not significant ($p \leq 0.064$–0.502), while the average of the 10 years is about 630 mm from the values of the three stations. Even when the *ET* values from OMSZ operational soil moisture model are accepted for the wider environment, they are not applicable for Kis-Balaton because off its moist endowments. *ET* values of wider environment are surmised to be underestimated.

Data from Keszthely was included in the *PET* studies for the longer period (1970–2012), since this is the closest station to the study area (Kis-Balaton) and it is situated at the side of the prevailing wind direction.

In the first step, *PET* values for Kis-Balaton between 1970 and 2012 were determined by the Antal-method, and they were compared to the results of OMSZ operational soil moisture model. *PET* of Kis-Balaton was determinable between 1993 and 2012 by Antal-formula with locally measured data. Correlation coefficient of calculated annual *PET* between using the Antal-formula and the soil moisture model of the OMSZ was acceptable, 0.781. It should be noted that in this period in the last, shorter section (1994–2012), the correlation coefficient was much higher (0.936). The stronger correlation can be explained by changes in observation methodology (from the early 90s, the manual observation was replaced by automatic weather stations). Looking at the annual *PET* data series (*Fig. 2*) it can be stated, that the nature of changes is similar, differences among the three curves are small, but sometimes significant. The annual *PET* calculated from the data of Keszthely is 5.2% ($p \leq 0.012$) higher than the *PET* calculated from the data of Kis-Balaton. Similarly, PET calculated from the OMSZ soil moisture model is 4.1% ($p \leq 0.008$) lower, than *PET* calculated from the data of Keszthely. There was no significant difference between *PET* calculated from the local data of Kis-Balaton and the data of the OMSZ model ($p \leq 0.54$). The difference between the annual *PET* sums from the two procedures is within ±140 mm. Values calculated from the data of Kis-Balaton headed between the two other curves, close to them. Years between 2000 and 2003 should be highlighted. At this period (very hot and dry), the values calculated from the local data are much lower. *PET* values based on local data were the lowest of all; the Antal-formula and the OMSZ operational soil moisture model exceeded *PET* with 110–261 mm and 73–167 mm, respectively. The reason might be the higher humidity values in the area of Kis-Balaton (wetland).

The slope of linear trend fitted to the data of the 43 years calculated for the data of Keszthely showed 3.7 mm increment per year ($p \leq 0.004$), while according to the OMSZ model it is 2.8 mm increase per year ($p \leq 0.046$). The linear trend forecast fitted to the data of Kis-Balaton was not significant ($p \leq 0.197$).

The most important statistical indicators of *PET* data set calculated by different approaches are summed in *Table 2*.

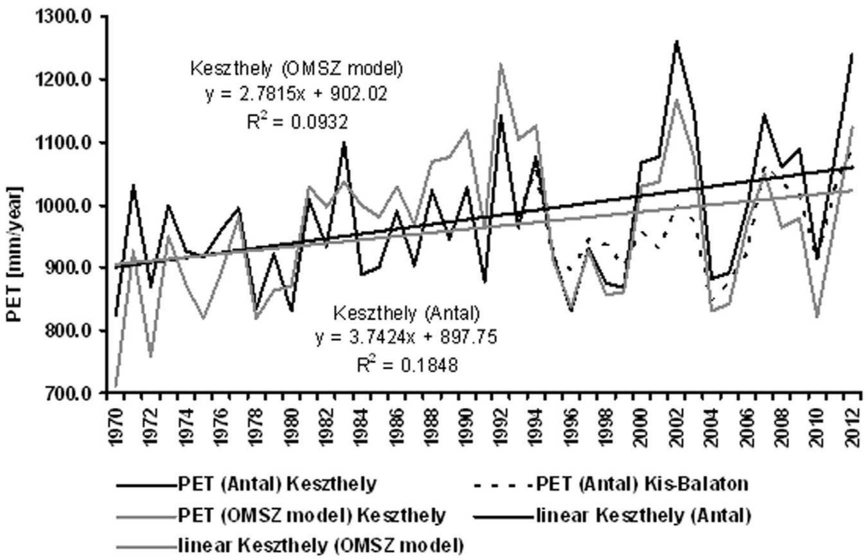

Fig. 2. Comparison of potential evapotranspiration (*PET*) calculated by using data of (i) Keszthely [*PET* (Antal) Keszthely]; (ii) the soil moisture model of the OMSZ (Hungarian Meteorological Service), and (iii) locally measured meteorological data [*PET*(Antal) Kis-Balaton]. We expressed PET after empirical equation processed by *Antal* (1968).

Table 2. Statistical parameters of potential evapotranspiration (*PET*)

	Avg.	Min.	Max.	SD	CV%
PET (Antal) Keszthely (1970–2012)	980	824	1261	109	11%
PET (Antal) Kis-Balaton (1993–2012)	963	844	1089	68	7%
PET (OMSZ model) Keszthely (1970–2012)	963	711	1224	114	12%

The monthly variation of *PET* within the year was analyzed, too (*Fig. 3*).

The maximum monthly *PET* was expected in July, the minimum in December. The difference between the two calculation methods was 7–10 mm in March, September, October, and under 6 mm in the other months. The share of the season from the annual PET was 740 mm, 75%.

Correlation among *PET* values calculated from the data of Keszthely and Kis-Balaton was very strong between 1993 and 2012, the correlation coefficient was 0.998. Thus the data of Keszthely can be converted into the data of Kis-Balaton (*Fig. 4*). There was no significant *SE* when the monthly evaporation sum was below 50 mm, however when it exceeded 100–150 mm, the *SE* was much higher weakening the accuracy of *ET* estimation.

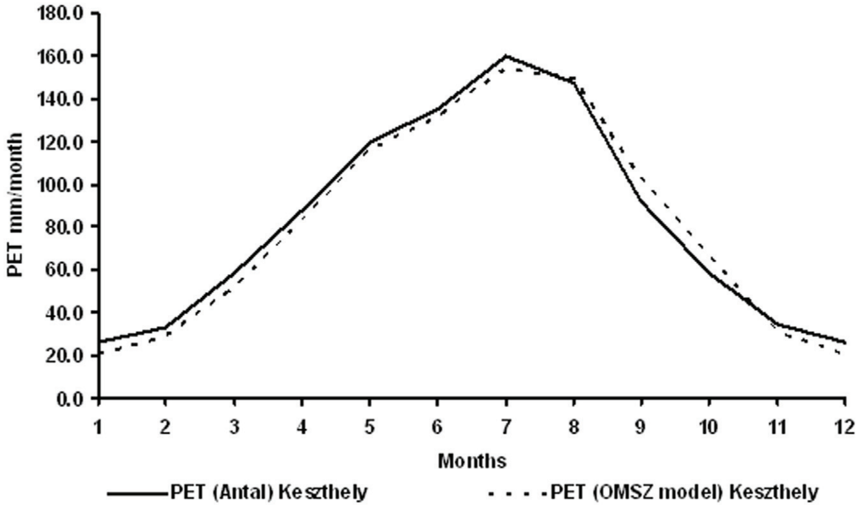

Fig. 3. Monthly means of potential evapotranspiration of Keszthely using the Antal-formula and the soil moisture model of the OMSZ between 1993 and 2012.

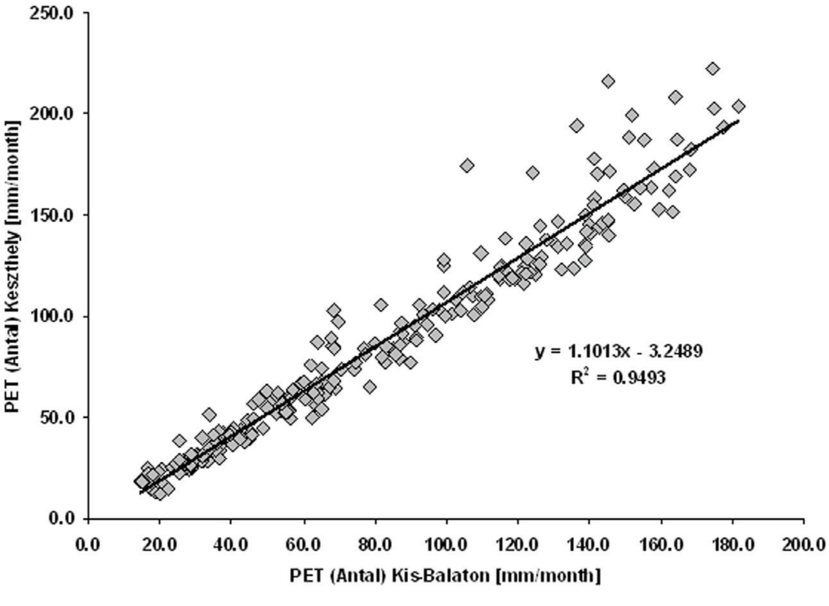

Fig. 4. Relationship between monthly calculated evapotranspiration from Keszthely meteorological data and locally measured meteorological data. To calculate *PET*, the Antal-formula was applied. The number of observed pairs was 240.

The estimation of *ET* for the area is a much more complex task, than the *PET* projection. Evaporation loss of water covered parts in the evaporation of Lake Fenéki is considered close to the potential, while at non-flooded parts, *ET* data seems to be useable. The *ET* of Lake Fenéki calculated by the OMSZ soil moisture model was not acceptable on annual basis (this model has been developed for average soil conditions, not for quasi wet environment). Regional evaporation of Lake Fenéki was examined between 1970 and 2012. The whole area is consistent for the years 1970–1992 in determining the evaporative water loss, since this is a period before the construction (partial flood). Since 1993 two parts of the lake are distinguished: (a) the flooded Grove Ingói and (b) the non-flooded (Outer Reservoir) Lake Fenéki.

The length of *ET* time series of Grove Ingói controlled by water balance was a 20-year period (*Fig. 5*). The values of annual *ET* were between 730 and 1070 mm, with an average of 890 mm, which was 70 mm, 8% ($p \leq 0.0001$) less, than those of *PET*.

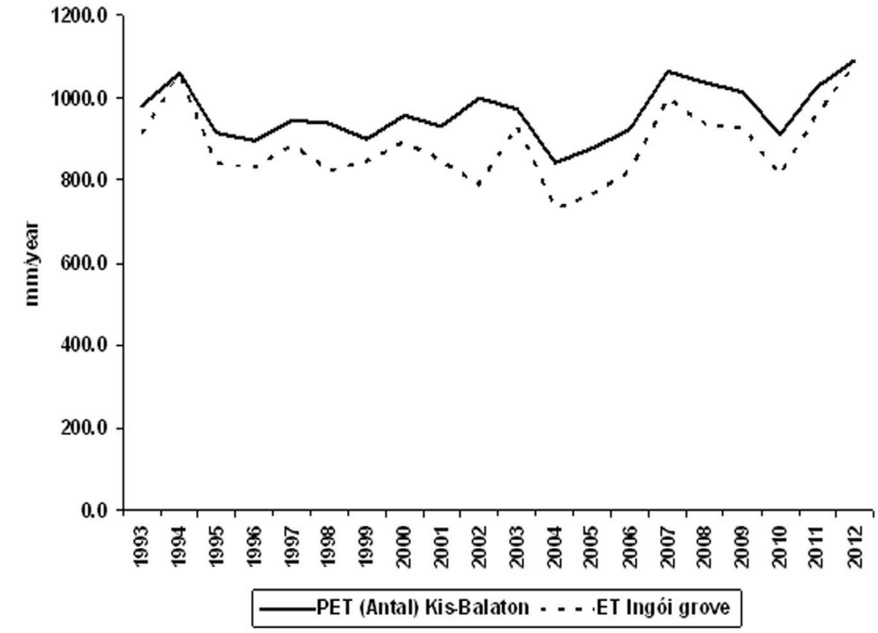

Fig. 5. The actual (*ET*) and potential (*PET*) evapotranspiration of Grove Ingói.

The estimation of evaporation for Lake Fenéki Outer Reservoir was prepared as well. Here Lake Fertő formula can not be used, since there is no permanent water cover. Water supply varying in time and space is typical for this area, which can not be followed exactly from the measured atmospheric data. Aerial photos were taken at the area (1988, 1992, 1993, 1994, 1995, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2008). According to them, the classification of the vegetation distribution (*Table 3*) was made as a starting base (*Pomogyi*, 2001; *Pomogyi et al.,* 1996). The year of 1992 is considered to be typical for the period before taking the aerial photos. 1992 was chosen in analysis, because the photos of 1988 were not detailed enough and the mapping methods were not up-to-date.

Table 3. Vegetation map data of Lake Fenéki Outer Reservoir

Lake Fenéki Outer Reservoir	**Avg [ha]**	**%**	**min**	**max**	**SD**	**CV%**
Reed	1 238	30%	1 117	1 363	74	0
Other wetland crops (marsh macrophytes)	1 753	43%	1 459	2 075	196	11
Swamp forest	177	4%	143	222	20	0
Herbaceous crops and grasses	387	9%	324	553	57	15
Wood	471	12%	309	588	114	24
Open water with seaweed	63	2%	12	99	27	42
Altogether	4 090	100%	4 064	4 107	12	0

According to the values of the table, open water surface occupies small area (2%). About 80% of the vegetation is considered to be well stocked with water similarly to wetland habitats. (In the especially dry years, lower percentage is expectable). For the characterization of the period between 1970 and 2012, precipitation data from Keszthely were used. The years were defined to be dry, when the lack of precipitation of the vegetation period exceeded the average of the period between 1970 and 2012 with 20%. These years were also warmer, than the average; their annual mean average temperature was 0.4 °C higher than the long-term average. Nine dry-warm years were found (1971, 1977, 1981, 1984, 1988, 1993, 2000, 2001, 2011), which is the fifth part of the whole period.

In the present processing, Eq. (4) was used for the estimation of *ET*. *Dunay et al.* (1968) based this method on the measurement data of “A” class evaporation pan, and suggested for the calculation of *PET*. This method was chosen, because the most of the area is a wetland well supplied with water, so a well-approximated estimation is expected. (Please note that *ET* was estimated by *Varga* (2005) for the non-flooded area, using *PET* values of the Antal-formula and the formula of *Turc* (1961) with a factor of 0.75 and 0.25.)

Application of the formula (4) was a good choice. The accuracy of calculated monthly *ET* values were checked using the monthly water balances for the period of 2003–2012. (Meteorological data used for the calculations were taken from the local measurements.) Estimation due to *PET* was quasi negated with the result that values measured with “A” class pans lag behind potential estimations. The average of the studied 10 years was 703 mm.

The evaporation of Grove Ingói and Lake Fenéki Outer Reservoir (real values, controlled with the water balance) was compared with the values of the “A” class pan at the study site (*Fig. 6*). *ET* of Grove Ingói between April and October (1998–2012) exceeded the *ET* calculated for Lake Fenéki Outer Reservoir with 14.4% ($p \leq 0.0001$). The data of “A” pan and *ET* calculated for

Grove Ingói differed with 24.1% ($p \leq 0.0001$) in the vegetation period between 1998 and 2012. The data of "A" pan and *ET* calculated for Lake Fenéki Outer Reservoir differed less, with 7.9% ($p \leq 0.0001$), as expected. *ET* is significantly underestimated in summer and autumn in the "A" pan, so its usage is not suggested for the estimation of evaporation at aquatic habitats.

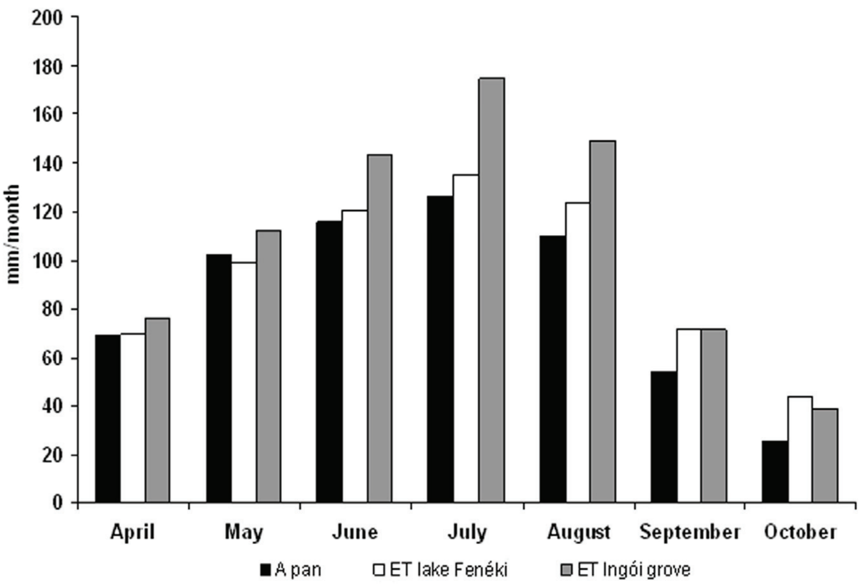

Fig. 6. Water losses calculated from water budget for Grove Ingói, Lake Fenéki Outer Reservoir and locally observed „A" pan evaporation (1998–2012).

Hereinafter, our calculations were extended to the period before the flood. The accuracy of *ET* calculated with Eq. (4) for Lake Fenéki Outer Reservoir was checked with the water balance, so this equation was adopted to the earlier period for the non-flooded area as well. Between 1970 and 2002, *ET* was calculated on a monthly basis. (The measured data of the OMSZ station in Keszthely were used.) Dataset checked with water balance was added to the values calculated with Eq. (4) for Grove Ingói before the flood (1970–1992). So a monthly data set for the period between 1970 and 2012 was made, from which annual *ET* was calculated. At Lake Fenéki Outer Reservoir for the whole period (1970–2012), *ET* was calculated with the Eq. (4). The data of the period between 1970 and 2012 were checked with the water balance. *ET* data set for the whole Lake Fenéki was made as well. Actual evaporation of Lake Fenéki for the period between 1970 and 2012 was derived from the calculated *ET* for Grove Ingói and Lake Fenéki Outer Reservoir, where the area ratio was taken into account (*Fig. 7*).

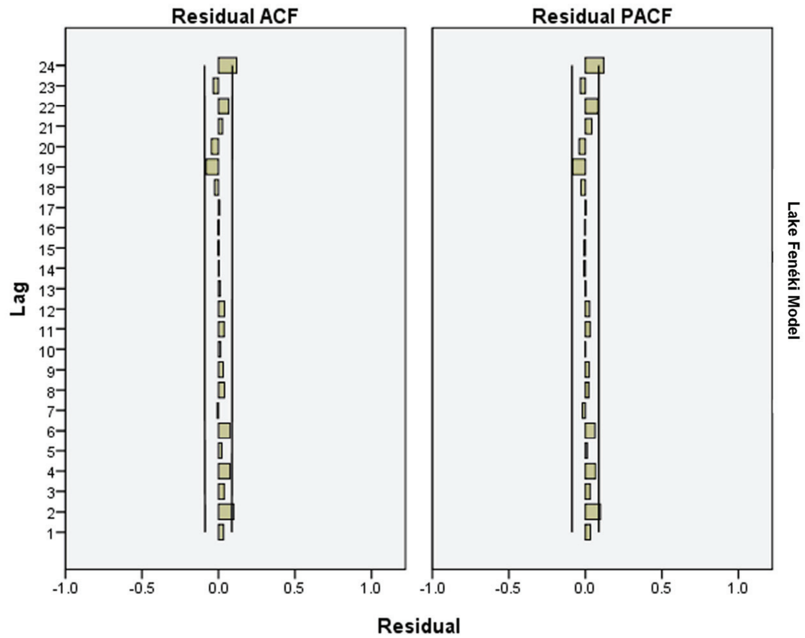

Fig. 7. Residuals (ACF and PACF) from the fitted ARIMA $(0,0,3)(0,1,1)_{12}$ for ET of Lake Fenéki.

The average annual evaporation of the whole period is 809.3±87.8 mm. If the nine dry-warm years are highlighted, their average annual evaporation exceeds the long-term average (874.7±37.6 mm) with 78 mm, with significantly lower standard deviation values. The average evaporation of the remaining wet-cold years is 796.6±89.4 mm. These years dominated (36 years), so sum of evaporation and standard deviation were close to the long-term average. None of the linear trends fitted to the two different periods (before and after the flood) were significant (1970–1992: $p \leq 0.144$; 1993–2013: $p \leq 0.366$).

In order to study *ET* time series of Lake Fenéki, an ARIMA model has been processed. We assumed that the process of *ET* was stochastic in nature. Therefore, we attempted to investigate the applicability of autoregressive integrated moving averages (ARIMA) modeling, a special time-series technique for developing forecast model for *ET*. In our study, the partial autocorrelation function (PACF) produced peak at lag 12, meaning that seasonal ARIMA $(0,0,3)(0,1,1)_{12}$ model is suggested to be the best fit for *ET* time series analysis.

To summarize *ET* seasonal variations in the present investigation, the SPSS time series modeller (http://www.spss.com) has shown that the seasonal ARIMA $(0,0,3)(0,1,1)_{12}$ model including additional seasonal term simply multiplied with the non-seasonal term has to be chosen. The reason of our choice was due to the fact that this model produced the lowest RMSE (quadratic scoring rule that measures the average magnitude of the error) and MAPE (mean absolute percentage error), equaling to 14.273 and 21.1%, respectively. The Ljung-Box-statistic (*Ljung* and *Box*, 1978) provided insignificant value of 0.398 meaning that there is no structure in the observed series, which is not accounted for by the model. For a model to be considered as adequate at describing evaporation time series, the residuals of the model have to be correlated; both ACF and PACF have to lie within limits counted by equation (*Fig. 7*). The residuals should be without pattern. As the Kolmogorov-Smirnov-test of noise residual indicated normal distribution, the multiplicative decomposition of time series was successful ($p \leq 0.535$). The estimated model parameters for ARIMA $(0,0,3)(0,1,1)_{12}$ computed by SPSS expert modeler are presented in *Table 4*.

Table 4. Estimated model parameters for seasonal ARIMA $(0,0,3)(0,1,1)_{12}$

				Estimate	**SE**	**t**	**Sig.**
Lake Fenéki Model	Square Root	MA	Lag 1	–0.224	0.043	–05.161	0.000
			Lag 3	–0.177	0.043	–4.065	0.000
		Seasonal Difference		1			
		MA, Seasonal	Lag 1	0.952	0.028	33.913	0.000

Based on RMSE value, seasonal ARIMA $(0,0,3)(0,1,1)_{12}$ was selected for forecasting of monthly *ET*, at Lake Fenéki (*Fig. 8*). *Fig. 8* also includes the upper and lower (UCL, LCL) values of an estimated confidence interval at 95% for the predictions. The chosen projected time period was only three years (2013–2015).

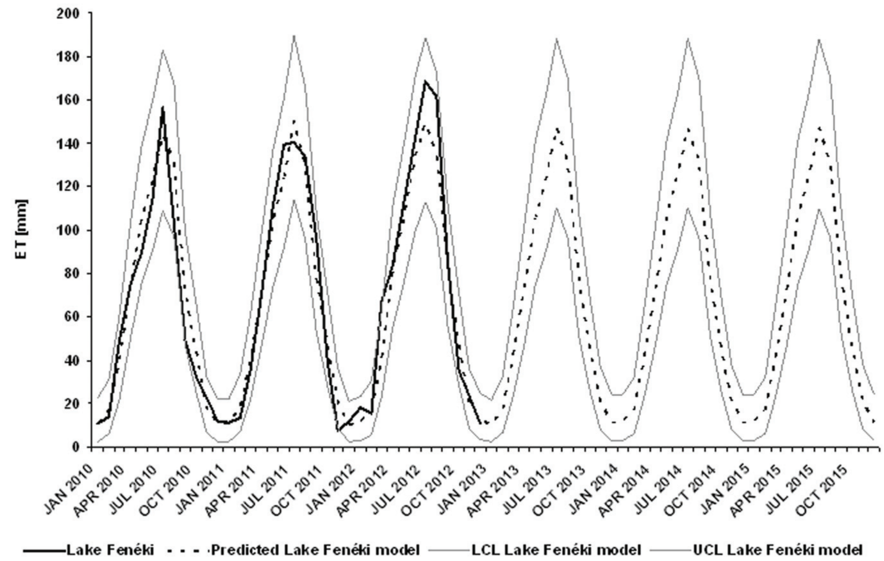

Fig. 8. The past and the future of the *ET*. Pattern of three-year actual and predicted *ET* data with three-year forecast (2013-2015) for monthly *ET* sums of Lake Fenéki by using the ARIMA $(0,0,3)(0,1,1)_{12}$ model. The LCL and UCL are the lower and upper limits of the confidence interval (95%), respectively.

The ARIMA $(0,0,3)(0,1,1)_{12}$ model parameters finalized for *ET* forecasting were as follows: $\theta_1=-0.224$, $\theta_3=-0.177$, $\Theta_1=0.952$. In our case D=1 (the order of seasonal differencing), s=12 (number of month per year). Seasonal pattern of *ET* series was also maintained in the projected values (see also *Table 4*).

4. Conclusions

Investigations were carried out on evaporation of Lake Fenéki (Kis-Balaton wetland) in the time period between 1970 and 2012. *PET* for the lake was generated using meteorological data of different stations. This study revealed that the locally measured meteorological values or regression equation derived from meteorological data of Keszthely would be appropriate in Lake Fenéki's *PET* calculation.

One part of the lake's observation site (Grove Ingói) has been artificially flooded in 1993. Irrespective to human intervention, the whole lake's spatial *ET* was statistically the same during the two time periods with modified watering levels (unflooded and flooded Grove Ingói). The long-term yearly *ET* averages of Lake Fenéki were 813 and 805 mm/year between 1970–1992 and 1993–2012, respectively. On the basis of fitted curves (*ET*), no significant trend has been confirmed either for the whole time period or after/before artificial intervention. Using trend analysis, we might conclude that in spite of flooding of Grove Ingói, there was no significant difference in long-term yearly *ET* sum of Lake Fenéki between 1972 and 2012. The probable reason might be the shortage of the used models. These formulas could not distinguish the various kinds of crop covers and their different evapotranspiration.

ET values of Lake Fenéki showed seasonal cycle, therefore, monthly data were used for generating a stochastic model. Investigation indicated that the seasonal ARIMA $(0,0,3)(0,1,1)_{12}$ model is a viable tool for studying long-term monthly *ET* data for Lake Fenéki. The generated *ET* values kept the earlier observed seasonal pattern, probably due to special wetland circumstances. The seasonal ARIMA $(0,0,3)(0,1,1)_{12}$ with lowest RMSE may also be selected for forecasting of monthly *ET* sums at Lake Fenéki (part of Kis-Balaton wetland, Hungary) using the following equation:

$$\left(1-B^{12}\right)X_t=\left(1-0.224B\right)\left(1-0.177B\right)\left(1+0.952B^{12}\right)\alpha_t, \qquad (11)$$

where X_t represents the time series data at period t. α_t represents a Gaussian white noise process (random shock) at period t. B represents a backward shift operator (*Box* and *Jenkins*, 1976).

Future research should be addressed to extend our results on other regions of Kis-Balaton wetland.

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