Assessment of uncertainty in estimating the evaporation from the Curonian Lagoon

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Abstract In this study, three methods of evaporation estimation (temperature-based ET_o [evapotranspiration] equations, radiation-based ET_o equations, and mass-transfer based ET_o equations) were applied to calculate the evaporation from the Curonian Lagoon. Estimation of evaporation by various methods showed that the annual mean of evaporated water from this shallow water basin during 1971–2011 ranged between 512–643 mm (average: 586 mm). The study revealed that Thornthwaite, Schendel, and Vikulina equations gave the most accurate assessment and the lowest uncertainties of evaporation (R of the calculated and the measured data ranged between 0.78–0.96). The value of evaporation depended on differences in estimated water surface area of the basin. The calculated evaporation using a constant surface area differed more than 10% from the one estimated according to the relationship between surface area and water level. However, these differences are minor in the context of the total water balance of the Curonian Lagoon, comprising only 0.06%–0.31% of the total water volume.

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INTRODUCTION

Assessment of evaporation from open water surfaces depends on many meteorological and environmental variables (such as solar radiation, atmospheric pressure, air and water temperature, air moisture, size and shape of evaporating water body, etc.). Understanding the lake evaporation process, establishing satisfactory calculation methods, and identifying the effects of lake evaporation on water resources and level are crucial tasks (Yao 2009).

Methods for estimating the evaporation from open water surfaces can be categorised into major types of approach: pan evaporation models, water balance models, energy budget models, mass transfer models, combination models of mass transfer and energy budget models, and empirical approaches (Xu, Singh 2002; Finch, Calver 2008). Winter *et al.* (1995) counted more than 30 equations proposed in various studies for determining the evaporation and evapotranspiration. Jensen (2010) summarized that the selection of

the best technique to use for a particular computation largely depends on data availability, type or size of the water body, and the required accuracy of the estimated evaporation. Abtew and Melesse (2013) added that the selection of a method for a specific application also requires evaluation of methods with respect to cost of data generation and stated that methods vary by complexity and input data requirements. Yao (2009) reviewed many study examples of long-term lake evaporation and stated that all the comparisons provided different conclusions depending on sites and data used.

Most of the employed equations often give a rough estimate of evaporation and are slightly outdated. The new ones differ from the old ones only slightly (usually in the empirical constants, which depend on the climatic and geographical conditions they are applied in). Uncertainties can originate in each step of evaluation of evaporation. Winter (1981) indicated that errors in estimates of evaporation could vary widely depending on instrumentation and methodology; according to this scientist, the energy budget is the most accurate method

(errors are in 10–15 percent range). Price *et al.* (2007) investigated variation and uncertainty in evaporation from subtropical estuary and found out that the uncertainty estimates derived from measurement errors in the data were 10 percent. In the water balance study of the Great Lakes immense hydrologic system, evaporation uncertainty was assumed to range between 10 and 35 percent (Neff, Nicholas 2005).

Lack of evaporation monitoring data should be mentioned in Lithuania. Some measurements were done from Lakes Sartai, Siesartis, Rudėsys, Glūkas, and Drūkšiai. The longest data series from a water surface are available for Lake Drūkšiai (observations from 1973 until 1997). These measurements were performed using floating evapometer on a GGI-3000 type raft (3000 is the water surface area of evapometer in cm^2) (Kriaučiūnienė *et al.* 2010). Study on evapotranspiration in meteorological conditions of Lithuania was performed using data from nearby Kaunas meteorological station (Nemčauskas, Pocienė 2000).

The aim of this study was to present the problems of estimation of evaporation (an important component of water balance) from the largest Baltic lagoon – the Curonian Lagoon and to identify the best methods for calculation of evaporation using direct evaporation measurement data from Lake Drukšiai.

3.8 m on average, with a maximum of 5.8 m. The lagoon contains about 6.2 km^3 of water; the water residence time is 81 day (Gailiušis *et al.* 2001). The northern part of the lagoon and the Klaipėda Strait are influenced by seawater intrusions from the Baltic Sea: according to the observation data of 2002–2010, salinity in this lagoon area is the greatest, exceeding 2.5‰. Salinity decreases to the south: it is about 1.2‰ near Juodkrantė, 0.08‰ near Nida, and 0.07‰ near Ventė (Dailidienė, Davulienė 2008). The southern and central parts of the lagoon are fresh water due to discharge from the Nemunas and other rivers. The whole Lithuanian part of the Curonian Lagoon belongs to NATURA 2000, a network of protected territories in Europe, connecting its most valuable natural habitats.

Lake Drūkšiai is the largest lake in Lithuania, located in the north eastern part of the country, on the Belarusian border (Fig. 1b). The area of the lake is 44.8 km^2, the maximum depth is 33.3 m, the average depth is 8.8 m, and the total water volume is 0.368 km^3 (Gailiušis *et al.* 2001). There are 11 tributaries to this lake and one river that outflows from it. In 1984, Lake Drūkšiai started to serve as a cooler for the Ignalina Nuclear Power Plant (INPP). The INPP consisted of two RBMK-1500 reactors: the first unit of the NPP began to operate in 1984, while the second was started in 1987. Their total maximum capacity was 2500

STUDY AREA

Coastal lagoons form along gently sloping coasts. They are usually connected to the open sea by inlets between barrier islands. They are poorly flushed, exhibit long residence times, and are ephemeral on a geologic time scale (Kjerfve, Magill 1989). The Curonian Lagoon is a shallow freshwater body in the south-eastern part of the Baltic Sea, separated from the sea by the barrier island Curonian Spit, which is a UNESCO World Heritage Site shared by two countries: Lithuania and Russia (Kaliningrad Oblast) (Fig. 1a). 381.6 km^2 of the northern part of the lagoon belongs to Lithuania. Its total surface area is 1584 km^2, the longest axis is 93 km, and the shortest axis is 46 km. Its depth is only

- Location of research objects

Nemunas - River
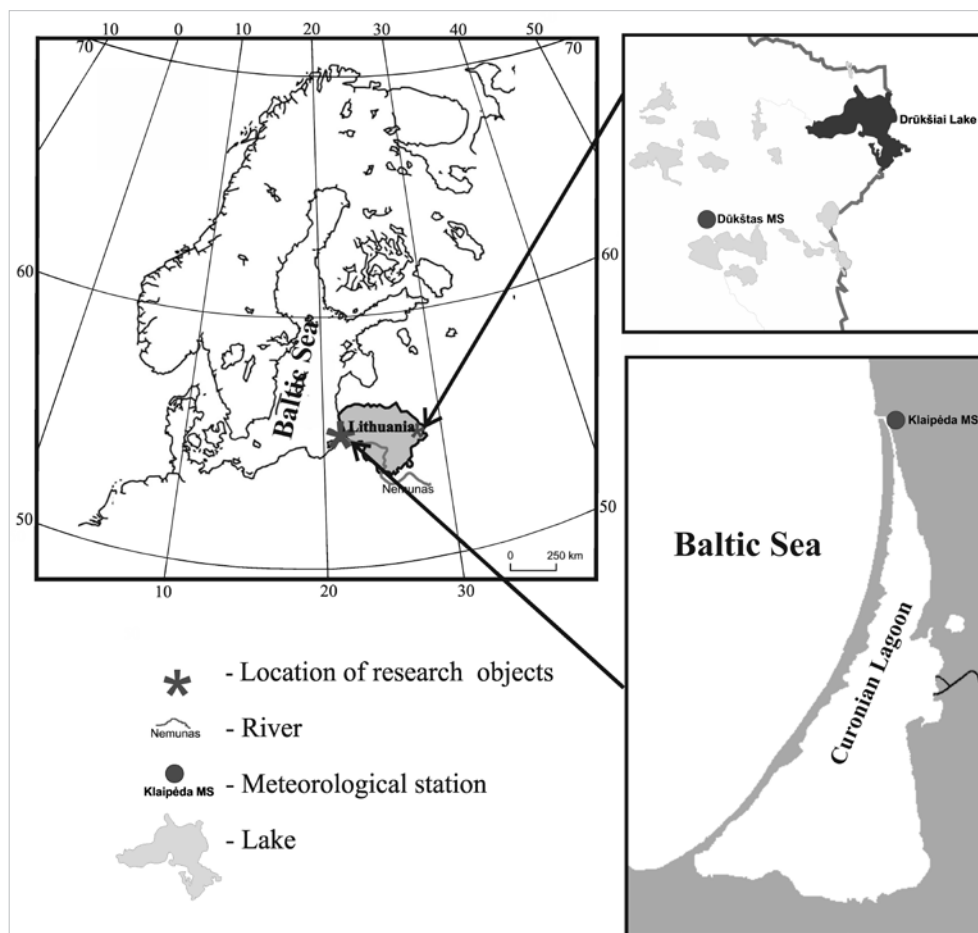
Klaipėda MS - Meteorological station

- Lake

Fig. 1 Location of the studied objects and meteorological stations. Compiled by D. Jakimavičius, 2013.

MW(e). 80 m³/s of water from the lake was used to cool one NPP unit. The decommissioning of the first unit was done in 2005, while the second unit was closed at the end of 2009. Operation of the INPP disturbed the natural hydrological and hydrothermal regime of the lake, as it intensified evaporation and influenced the hydrochemical processes (Kriaučiūnienė *et al.* 2010).

DATA AND METHODS

The authors managed to find a few studies of water balance of other Baltic Sea lagoons: the Vistula (Silicz 1975) and the Darss Zingst Bodden Chain (Schlungbaum, Baudler 2001). However, such studies of the Curonian Lagoon have continued since the middle of the 20ᵗʰ century. E. Červinskas (1956) was the first who calculated the water balance of the Curonian Lagoon. J. Dubra continued and revised the estimation of the calculations (Dubra 1978). The water balance of the Curonian Lagoon for the long period (1955–1995) was analysed by B. Gailiušis *et al.* (2001). All the components of the water balance were established using direct measurement data, which added accuracy to the work. Various proposed estimates of evaporation as an element of water balance of the Curonian Lagoon were discussed by Jakimavičius and Kriaučiūnienė (2013).

Daily average data from Klaipėda meteorological station (MS), including air temperature in ᵒC (average, minimal and maximum), wind speed in m s⁻¹, relative humidity in %, and vapour pressure deficit in hPa of the period from 1971 to 2011 were used for calculation of evaporation from the Curonian Lagoon. The above listed meteorological data from Dūkštas MS of 1974–1983 were selected for the comparative analysis of the measured and calculated evaporation values.

Many different methods are proposed for calculation of evaporation from an open water surface, i.e. water budget, energy budget, mass transfer (aerodynamic), combination of mass transfer and energy budget, and pan evaporation methods (Xu, Singh 2002). Water budget method is recommended to be used in cases when all other components of water balance are known (then evaporation can be derived from the water balance equation). However, this method has its downsides. Firstly, it requires very complicated water balance calculations based on a vast amount of meteorological information. Moreover, potential calculation errors can be several times higher than the total evaporation. Water budget method was rejected in this estimation of evaporation because of particularities of its application. Pan evaporation method is based on direct measurements, and since such measurements are not available for the Lithuanian part of the Curonian Lagoon, this method is not appropriate for this water body as well. Evaporimeter method was used when the measured value of evaporation was compared with the calculated one (the case of Lake Drūkšiai) in order to

identify the most accurate technique in the conditions of Lithuania. In this study three methods of estimating evaporation were selected: 1) temperature based ET_o (evapotranspiration) equations, 2) radiation based ET_o equations, 3) mass transfer based ET_o equations (Table 1). The Thornthwaite, Schendel, and Hargreaves and Samani equations were chosen to represent the first approach of estimation. The Irmak and modified Penman–Monteith equations belong to the second group, which is based on estimation of solar radiation. The mass-transfer method is one of the oldest methods, based on Dalton's gas law (Dalton 1802). Five selected equations (Table 1) are modified Dalton equations adjusted for certain territories.

The uncertainty of the calculated results of evaporation from the Curonian Lagoon depends on the accuracy of measured meteorological parameters used in equations. Average, minimal and maximum temperatures are measured with 0.2ᵒC accuracy, while the error in measuring wind speed may reach 1.5%. Possible inaccuracies of such measurements can influence the calculated values of evaporation.

The best estimate approach provides sufficient information and evaluates possible uncertainties of physical processes. The GRS method developed in the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) (Hofer 1999) was used in this study. The GRS method is based on a probabilistic quantification of the uncertainty of studied parameters.

The main steps of this method are:
- Identification of potentially relevant uncertainties of meteorological parameters which are used in evaporation calculation according to different selected methods.
- Definition of uncertainty ranges, i.e. minimum and maximum values.
- Specification of probability distributions over these ranges. Gaussian and uniform distributions are usually used in the absence of deeper knowledge on parameter uncertainty.
- Identification and quantification of dependencies between parameters, if present.
- Generation of a random sample of size *n* for parameters from their probability distributions by Monte Carlo method.
- Evaporation calculation according to different methods using generated parameter sets.
- Calculation of quantitative uncertainty statements, e.g. 5% and 95% quintiles or two-sided statistical tolerance limits like upper and lower limit values with 95% probability content and inside the 95% confidence interval.
- Calculation of quantitative sensitivity measures (Spearman's correlation coefficient) to identify the uncertain parameters which contribute the most to the uncertainty of the results.

The main advantage of the selected GRS method, based on proven statistical procedures, is that the

Table 1 Equations for estimating evaporation according to three methods. Compiled by D. Jakimavičius, 2013.

Method	Equations	Parameters
Temperature based ET_o equation	Thornthwaite 1948: $$ET_o = 16 \times \left(\frac{10 \times T}{I} \right)^a \times \frac{\mu \times N}{360}$$ Schendel 1967: $$ET_o = 16 \times \frac{T}{RH}$$ Hargreaves and Samani 1985: $$ET_o = 0.408 \times 0.003 \times (T+20) \times (T_{max} - T_{min})^{0.4} \times R_a$$ $$ET_o = 0.408 \times 0.0025 \times (T+16.8) \times (T_{max} - T_{min})^{0.5} \times R_a$$	ET_o is evapotranspiration (mm day^{-1} or mm month^{-1}); T, T_{max} and T_{min} are the mean, maximum and minimal air temperatures, (°C); I is the annual heat index; a is an exponent in function of the annual index; μ is the number of days per month; N is the maximum number of sunny hours in function of the month and latitude; RH is the relative humidity (%); R_a is the extraterrestrial radiation (MJm^{-2} day^{-1}); R_s is solar radiation (MJm^{-2} day^{-1}); λ is the latent heat flux (2.45 10^6 J kg^{-1}); ρ_w is the density of water (1000 kg m^{-3}); u is the wind speed (m s^{-1}); d is vapour pressure deficit (hPa);
Radiation based ET_o equation	Irmak *et al.* 2003: $$ET_o = -0.611 + 0.149 \times R_s + 0.079 \times T$$ $$ET_o = -0.642 + 0.174 \times R_s + 0.0353 \times T$$ $$ET_o = -0.478 + 0.156 \times R_s - 0.0112 \times T_{max} + 0.0733 \times T_{min}$$ Kay and Davies 2008 $$ET_o = \begin{cases} \dfrac{R_a \times (T+5)}{\lambda \times \rho_w \times 100} & if\,(T+5) > 0 \\ 0 & \text{otherwise} \end{cases}$$	
Mass transfer based ET_o equation	Vikulina 1979: $$E = 0.14 \times (1 + 0.74 \times u) \times d$$ Dalton 1802: $$ET_o = (0.3648 + 0.07223 \times u) \times d$$ Trabert 1896: $$ET_o = 0.3075 \times \sqrt{u} \times d$$ Meyer 1926: $$ET_o = (0.375 + 0.05026 \times u) \times d$$ WMO 1966: $$ET_o = (0.1298 + 0.0934 \times u) \times d$$ Mahringer 1970: $$ET_o = 0.15072 \times \sqrt{3.6 \times u} \times d$$	

number of calculations is independent of the number of uncertain parameters to be investigated. The number of calculations necessary for one-sided or two-sided tolerance intervals depends only on the required probability and the confidence level of the statistical tolerance limits. The relationship between these parameters is described by Wilks' formula for two-sided statistical tolerance intervals, where (b × 100%) is the confidence level (Wilks 1941):

$$(1 - a^n) - n(1-a)a^{n-1} \geq b \qquad (1)$$

For a 95% probability and a confidence level of 95%, a number of calculations (n=93) must be performed.

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Sensitivity analysis by using Spearman's correlation coefficient techniques allows the ranking of the uncertain meteorological parameters in relation to their contribution to the output uncertainty (evaporation calculation results). Spearman's correlation coefficient assesses how well the relationship between the two variables can be described using a monotonic function. If there are no repeated data values, a perfect Spearman correlation of +1 or −1 occurs when each of the variables is a perfect monotone function of the other (Myers, Well 2003). The X_i, Y_i are converted to ranks x_i, y_i, and Spearman's correlation coefficient (ρ) is calculated as follows:

$$\rho = \frac{\acute{O}_i(x_i - \bar{x})(y_i - \bar{y})^2}{\sqrt{\acute{O}_i(x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}} \qquad (2)$$

The SUSA (Software System for Uncertainty and Sensitivity Analyses) software is developed by GRS and provides a choice of statistical tools to be applied during the uncertainty and sensitivity analysis (Kloos, Hofer 2002). The SUSA software was applied to implement the GRS method. This software is used to generate a random sample of size n for model parameters (by Monte Carlo method) and to calculate sensitivity (Spearman's correlation coefficient) and uncertainty statements.

RESULTS

Variation of evaporation depending on the estimation method

In this study, 14 different equations were applied to calculate evaporation from the Curonian Lagoon during the period of 1971–2011. Evaporation values were generalised according to three groups of methods (temperature based, radiation based, and mass transfer based ET_o equations) (Fig. 2, a–c) and average values of all equations of each group were calculated (Fig. 2, d).

The results of comparison of different methods revealed the highest differences of estimated evaporation from the Curonian Lagoon in the cold period of a year, i.e. in November–February. In this period, the evaporation estimated by different techniques varied considerably (54.4 times in December, 37.7 in November, 10.7 in February, and 9.8 in January). Such great differences can be explained by specificity of each methodology. For example, evaporation estimated by temperature based and radiation based equations depends on air temperature that has negative values in the cold period, therefore the calculated value of evaporation is very small or equals zero. In mass transfer equations, evaporation is influenced by humidity deficit and wind speed, therefore its value calculated by this technique is usually higher than calculated by
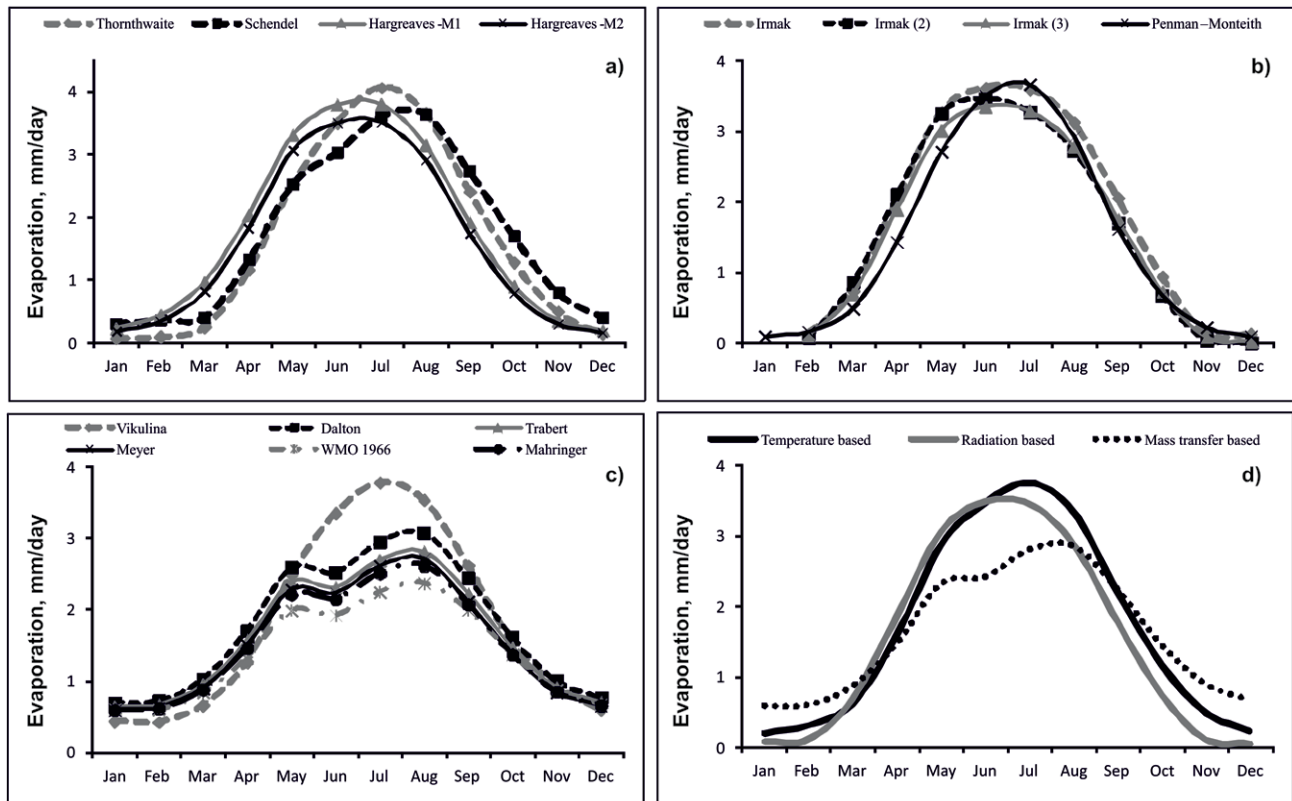

Fig. 2 Variation of evaporation from the Curonian Lagoon depending on the estimation methods in 1971–2011: a) temperature based ET_o equations, b) radiation based ET_o equations, c) mass transfer based ET_o equations, d) averages according to three methods. Compiled by D. Jakimavičius and J. Kriaučiūnienė, 2013.

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the other equations. In spring, the differences given by various equations were not as significant as in winter and comprised from 1.7 (in May) to 4.1 (in March) times. In the summer period, these differences varied from 1.5 (in August) to 2 (in June) times, whereas in autumn (September–October) they were higher than in summer and lower than in spring, varying from 1.7 to 2.6 times.

During the analysis of annual evaporation from 1971–2011, it was identified that the highest values of evaporation were estimated by Vikulina equation (659 mm) and the lowest – according to the equation proposed by the World Meteorological Organisation (WMO) in 1966 (512 mm) (Table 2). According to temperature based equations, average estimated evaporation was 615 mm, according to mass transfer equations – 591 mm, and according to radiation based equations – 556 mm.

Comparison of the calculated and measured evaporation values

Many different equations are applied to calculate evaporation (14 were used in this study), however they are usually adapted to a certain region. Comparison of measured values of evaporation with calculated ones using various equations was performed in order to find out a suitability of each equation for the Lithuanian region.

Only few evaporation measurement data from large water bodies are available in Lithuania. Multi-annual measurements were carried out only in Lake Drūkšiai in 1974–1983 (May–October) before the construction of Ignalina Nuclear Power Plant (INPP). INPP began to operate and release the heated effluents to the lake in 1983. Consequently, the thermal regime of the lake was changed and evaporation from the water surface increased (Kriaučiūnienė *et al.* 2010). The measured

Table 2 Seasonal and annual evaporation from the Curonian Lagoon in 1971–2011. Compiled by D. Jakimavičius and J. Kriaučiūnienė, 2013.

Evapora-tion in the season, mm	ET_o equations													
	Temperature based method				Radiation based method				Mass transfer based method					
	Thornthwaite	Schendel	Hargreaves-M1	Hargreaves-M2	Irmak	Irmak (2)	Irmak (3)	Penman–Monteith	Vikulina	Dalton	Trabert	Meyer	WMO 1966	Mahringer
Winter	9.0	32.3	24.8	19.6	7.4	1.9	3.4	9.2	43.5	65.5	59.8	55.6	56.5	55.6
Spring	120.7	130.8	193.5	174.8	184.4	190.2	170.8	141.3	135.1	163.0	149.8	143.1	126.8	139.3
Summer	344.2	315.9	329.0	304.4	316.0	289.0	288.0	308.3	326.4	262.1	239.5	231.5	200.3	222.7
Autumn	126.6	158.5	95.8	85.4	94.3	72.3	77.5	75.5	153.6	152.8	139.4	130.9	128.3	129.6
Annual	600	638	643	584	602	553	540	534	659	643	588	561	512	547

Variation of evaporation depending on different estimation of water surface area

Correct evaluation of the water surface area of the Curonian Lagoon is equally important to the right choice of calculation technique for estimating evaporation. The lagoon water surface area is 1584 km^2, but it depends on the water level (Červinskas 1972). The average lagoon water surface of each month of 1971–2011 was calculated using a bathygraphic curve. Evaporation was estimated in two ways: 1) the water surface area of the Curonian Lagoon was considered a constant, i.e. 1584 km^2; 2) the lagoon water surface area for each month was calculated according to dependence between surface area and water level. The results showed 6.9% higher evaporation values estimated using the dependence (Fig. 3). Higher differences between estimated values using the selected ways were identified in the winter and autumn months (11.1% and 7.8% respectively) and lower in the spring and summer months (4.5% and 4.2% respectively).

evaporation data of natural lake regime were used in this study. According to different methods, the estimated value of evaporation from Lake Drūkšiai was not always close to the measured one (Fig. 4).

The widest range of values was determined in May, September and October (Fig. 4). Evaporation
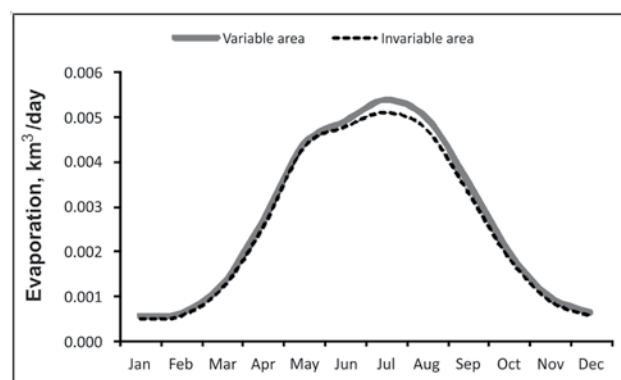

Fig. 3 Evaporation from the Curonian Lagoon in 1971–2011 estimated by different method of water surface area evaluation. Compiled by D. Jakimavičius and B. Gailiušis, 2013.
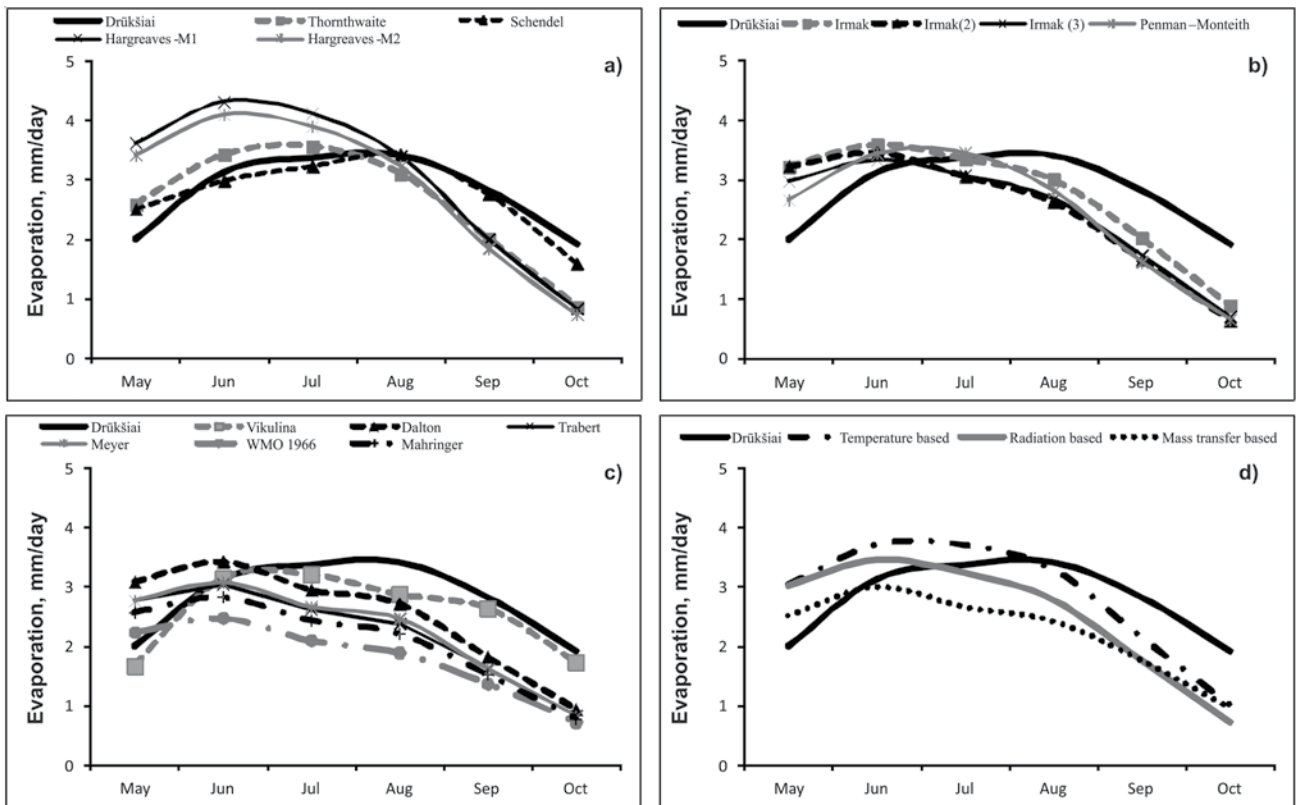
Fig. 4 Comparison of measured evaporation values from Lake Drūkšiai with values calculated using different methods for the period of 1974–1983: a) temperature based ET_o equations, b) radiation based ET_o equations, c) mass transfer based ET_o equations, d) average values of all methods. Compiled by D. Jakimavičius and D. Šarauskienė, 2013.

in May calculated according to all equations (except by Vikulina) was higher than the measured value from 12.7% (by WMO 1966) to 82.3% (by Hargreaves-M1). Evaporation in September and October calculated according to various techniques was less than the measured one from 2.3% (by Schendel) to 66.7% (by Irmak (2)). In search of the proper equation, the annual sum of evaporation has to be considered as well. Analysis revealed that in the studied period (1974–1983), the smallest difference was observed

between the measured values and the values calculated by Schendel equation (–0.6%). Calculation using the rest of the equations resulted in differences from –34.8% to +10.2% (Table 3).

Defined correlations and estimated small differences between the measured and calculated values of evaporation enable to conclude that Schendel (E –0.6%, R=0.91), Vikulina (E –8.1%, R=0.96), and Thornthwaite (E –6.5%, R=0.78) equations (Table 3) are the most appropriate for estimating evaporation

Table 3 Correlations between the measured and calculated values of evaporation from Lake Drūkšiai. Compiled by D. Jakimavičius and D. Šarauskienė, 2013.

| | Real | ET_o equations | | | | | | | | | | | | |
| | | Temperature based method | | | | Radiation based method | | | | Mass transfer based method | | | | |
	Drūkšiai	Thornthwaite	Schendel	Hargreaves-M1	Hargreaves-M2	Irmak	Irmak (2)	Irmak (3)	Penman–Monteith	Vikulina	Dalton	Trabert	Meyer	WMO 1966
Correlation with measured evaporation	–	**0.78**	**0.91**	0.60	0.60	0.58	0.47	0.56	0.68	**0.96**	0.50	0.49	0.51	0.47
Average evaporation, mm	508	475	505	560	528	492	449	444	449	467	457	407	411	331
±E, %	–	-6.5	-0.6	10.2	3.9	-3.1	-11.6	-12.6	-11.6	-8.1	-10.0	-19.9	-19.1	-34.8

from large water bodies in Lithuanian territory. Application of the other selected equations gave worse results, however these techniques may be successfully used in other regions.

Uncertainty analysis

Since the highest evaporation was identified in the summer period, uncertainty analysis was performed for the data of June–August. One equation was selected from each method group (Hargreaves-M1, Irmak and Mahringer). Uncertainty of calculation depends on the accuracy of equation parameters. For instance, air temperature (average, max and min) from Hargreaves-M1 and Irmak equations is measured with 0.2 ºC accuracy; wind speed used in Mahringer equation can have 1.5% inaccuracy; and humidity deficit correctness depends on the air temperature, because it is calculated according to the dry and wet thermometer readings.

Applying the SUSA software package, one hundred sets were generated for each day of the investigated period (June–August of 2003). Spearman's correlation coefficient was used to evaluate the influence of meteorological parameters on the calculation results of evaporation from the Curonian Lagoon. The greater absolute value of Spearman's correlation coefficient means that the parameter had a greater impact on the calculation results. The Spearman correlation coefficients calculated for each of the meteorological parameters revealed that the results of Hargreaves-M1 and Irmak equations mostly depended on minimum air temperature, T_{min} (–0.67 and –0.68 respectively) and maximum air temperature, T_{max} (0.63 and 0.64 respectively), and relied the least on the average values of air temperature, T (0.15 and 0.11 respectively) (Figures 5a, 5b). In the application of Mahringer equation, the correct evaluation of humidity deficit had the greatest influence (0.81) on the results, while wind speed was less important (0.57) (Fig. 5c). According to the accomplished analysis, evaporation deviated from the average value by ±1.6% when estimated by Hargreaves-M1 equation, ±1.5% by Irmak equation, and ±1.1% by Mahringer equation. The uncertainty analysis indicated that the influence of the accuracy of meteorological parameter measurements on estimating evaporation from the Curonian Lagoon according to various techniques is not significant (difference from the calculated value can reach up to 1.6%).

DISCUSSION

Different methods for estimating evaporation are applied in different countries. Fourteen equations that represent three methods were selected for calculation of evaporation from the Curonian Lagoon. The results varied significantly from 512 to 659 mm. In order to identify the calculated values that are the closest to the measured ones, a comparative analysis was performed. Multiannual measured data of evaporation from Lake Drūkšiai was used. It was determined that Thornthwaite, Schendel, and Vikulina equations gave the most accurate evaluation of evaporation (R between the calculated and the measured data varied from 0.78 to 0.96). Therefore Schendel and Vikulina calculation techniques were suggested for estimating evaporation from the Curonian Lagoon (as well as from other Lithuanian lakes and reservoirs) when there is a large amount of meteorological information. In cases when the available information is not sufficient or only evaporation projections are performed (because only the average air temperature is necessary for such calculation), the Thornthwaite equation should be applied. According to the proposed techniques, the calculated evaporation varied from 600 mm (by Thornthwaite) to 658 mm (by Vikulina). The rest of
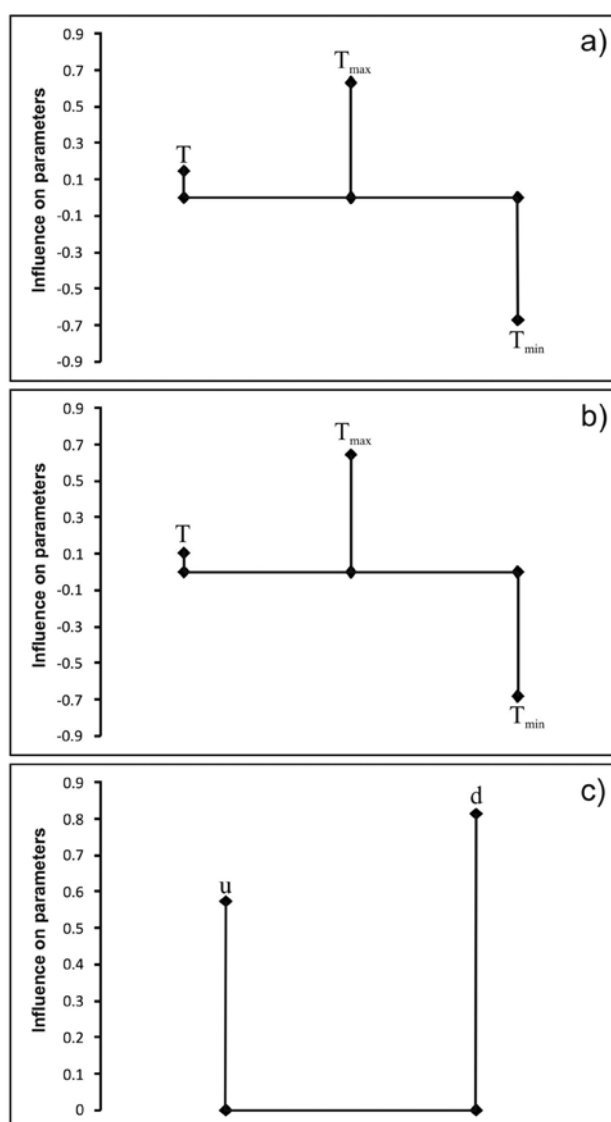

Fig. 5 The influence of input parameters to the calculation results of evaporation according to: a) Hargreaves-M1, b) Irmak, c) Mahringer equations. Compiled by D. Jakimavi-čius, 2013.

analysed methods underestimate evaporation and are not suitable for the conditions of Lithuania. Similar comparative analysis was performed in Lithuania, but estimates were made for evapotranspiration (Nemčauskas, Pocienė 2000). This study showed that evapotranspiration calculated according to Thornthwaite correlated well with the measured one in specially equipped research polygons (R was from 0.73 to 0.89). Similar comparison made for Lake Ontario by Xu and Singh (2001) also revealed that evaporation estimated by Thornthwaite and Hargreaves had high correlations with the measured values (R 0.81–0.90). Thornthwaite equation for estimating evaporation was used in other studies of Lithuanian scientists (Kilkus *et al.* 2006; Stonevičius *et al.* 2008; Taminskas *et al.* 2007) as well. Therefore studies of Lithuanian scientists as well as foreign research works confirm that in many cases evaporation estimation method proposed by Thornthwaite is the best choice and it can be successfully applied in Lithuania.

The choice of the right method for estimating calculation and accuracy of meteorological parameters had the greatest influence when calculated evaporation from the Curonian Lagoon was expressed by layer height (e.g. in mm). Inaccuracies originated during the measurement of meteorological parameters can create 1.1–1.6% errors in evaporation estimates. When calculating evaporation expressed in volume units (e.g. km^3), the final result depended mostly on the correct assessment of the surface area of researched water body. Due to different way of area evaluation (using an average water surface area or an area depending on the water level), the difference between evaporation values can be as high as 11.1%. However, these seemingly significant differences equal only from 0.06% to 0.31% of the total water amount of the Curonian Lagoon, because the average annual losses are 28.648 km^3 (Jakimavičius, Kriaučiūnienė 2013). In their assessment, Lowe *et al.* (2009) also assumed that this source of uncertainty is generally small compared to the others.

CONCLUSIONS

Estimation of evaporation by various methods showed that the annual mean of evaporated water from the Curonian Lagoon in 1971–2011 was 586 mm (from 512 to 643 mm). The greatest differences were identified between the values calculated for the winter season and the smallest – for the summer season.

Comparison of measured evaporation values (based on Lake Drūkšiai data) with calculated ones revealed that Thornthwaite, Schendel, and Vikulina equations gave the most accurate evaluation (R between the calculated and the measured data was 0.96, 0.91, and 0.78 respectively). According to these equations, the calculated values of evaporation from the Curonian Lagoon water surface varied from 600 mm (by Thornthwaite) to 658 mm (by Vikulina).

Evaluation of changes of water surface area that depend on water level fluctuations is very important when calculating the evaporation from large water bodies. The performed analysis indicated that calculated evaporation from the Curonian Lagoon using a constant surface area can differ more than 10% from the one estimated according to the relationship between surface area and water level.

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