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Evaporation from surface of lakes

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Abstract: Monthly totals of actual evaporation obtained from an evapometric raft installed on Lake Rajgrodzkie were compared with monthly totals of evaporation from the water surface calculated using the Penman and Davydov formulae.

Key words: evaporation from water surface, Lake Rajgrodzkie

Introduction

The evaluation of evaporation from the lake surface is difficult owing to the complex character of moisture and heat exchange processes which occur between water and air and depend both on climatic conditions and morphometric traits of water bodies.

The evaporation from he water surface is most frequently determined using indirect methods such as heat balance, turbulence diffusion (Jurak 1976) or empirical formulae. The most precise direct measurements are rarely used. They can be carried out using different types of evapometers, the obtained results being extrapolated to whole water bodies (Bac 1968, Demiańczuk 1967, Jurak 1970). In practice these methods are rarely used since the floating evapometric stations are scarce and a grater number of meteorological data must be available.

The evaporation from the lake surface is most frequently estimated from empirical formulae which take into consideration meteorological factors significant in the evaporation process (e.g. Davydov 1944, Penman 1956, Demiańczuk 1967, Jaworski 1980). The application of these formulae allows a rough estimate of evaporation from the surface of a water body. Individual traits of lakes cause significant differences in the magnitude of evaporation from the water and any attempts of introducing certain morphometric elements of lakes into the formula bring about its complication and difficulties in its application. In many cases the complex character of empirical formulae is not associated with precise estimates of evaporation from the water surface.

The simplest formulae with a few meteorological elements are most frequently used in practice (e.g. Bac and Rojek 1999, Bajkiewicz-Grabowska 2002). They are applied in the calculation of monthly and annual sums of evaporation from the water surface.

In a new program of limnological investigations the Institute of Meteorology and Water Economy installed two evapometric rafts on lakes Raduńskie Górne (Kashubian Lakeland) and Rajgrodzkie (Mazurian Lakeland) in 2005. Up to now the investigation was only carried out on Lake Sławskie. These are pilot studies permitting the estimation of evaporation in the summer half year.

The pattern of investigations

The presented paper concerns the comparison of monthly evaporation sums from the water surface, measured using a floating evapometer on a raft of GGI-300 type on Lake Rajgrodzkie, with monthly evaporation sums from the water surface measured using the most frequently applied empirical formulae. The compared periods are summer seasons (May-October) of 2005 and 2006. The following measurements are carried out on the evapometric raft: water temperature in the lake and in the evapometer at the altitude of 2 m; elements of moisture deficiency (the

August psychometer); maximum and minimum air temperatures; and the daily wind velocity.

The evaporation from the water surface measured using a floating evapometer was converted into actual evaporation according to the dependence:

$$E = 0{,}8\ E^{*}\frac{e_0 - e_2}{e_0^{*} - e_2} \tag{1}$$

where : E* - instrument coefficient of GGI-3000 evapometer; e – vapour pressure determined on the basis of lake water temperature; e* - vapour pressure determined on the basis of water temperature in the evapometer; e_2 – vapour pressure at the altitude of 2 m.

Monthly totals of actual evaporation were compared with the evaporation calculated on the basis of the simplest and most often used empirical formulae which allow the estimation of monthly evaporation totals from the water surface; i.e., the Penman formula

$$E = 0{,}36\ i\ d\ (1+0{,}5V) \tag{2}$$

and the Davydov formula

$$E = 15\ d^{0{,}8}\ (1+0{,}125V) \tag{3}$$

where: d – moisture deficiency (in mm); V – wind velocity (in m s^{-1}); I – number of days in months.

Since in general it is accepted that the results of the Penman formula of calculating the potential evaporation approximate to the evaporation from the water surface, the calculations according to this formula also were compared with the results of direct measurements. The concept of this formula is the determination of flow density of latent heat according to the dependence

$$E = \frac{\frac{\Delta}{\gamma}(R_n + G) + E_a}{\left(1 + \frac{\Delta}{\gamma}\right)} \tag{4}$$

where: irradiation balance; G – soil heat flow; Δ/y – coefficient determining the participation of energy flow; E – evaporation capacity of air.

The result is obtained in Wm^{-2} and in order to express it in millimeters the resulting value must be transformed as follows:

$$E\ [mm] = \frac{E\ [W m^{-2}]}{28{,}34} n \tag{5}$$

where: n – number of days; 28.34 – coefficient converting the density of energy flow used in evaporation.

The calculation of monthly evaporation totals using formulae (2), (3), (4,5) was based on meteorological data from the measuring station on the evaporation raft and data from the Biebrza land station, 12 km southwest of Lake Rajgrodzkie.

The meteorological observations and evaporation measurements on the evapometric raft begun in June 2005, the favourable weather conditions permitting to finish them early in December. In 2006 the observations on the raft were carried out from May to November. Monthly evaporation totals obtained on the basis of the Penman formulae (2) and (4,5) approximate to the values of the actual evaporation from the evapometric raft (Fig.1). In 2005 seasonal evaporation sums calculated using formula (2) were 16% lower than the actual evaporation from the raft and did not differ from those in 2006. The seasonal sums of potential evaporation (formulae 3 and 4) were 25% lower in 2005 and 9% lower in 2006.

However, the seasonal evaporation totals calculated using the Davydov formula (3) considerably differed from the actual evaporation, being 49% lower in 2005 and 40% lower in 2006.

In comparison with seasonal sums the monthly totals of evaporation showed much greater differences (Fig.1, Table 1). Compared with the actual evaporation the evaporation calculated using the best adapted Penman formulae (2) and (4,5) showed deviations in two directions. In November 2005 the total evaporation calculated using formula (2) was 44% of the actual evaporation while in May 2006 – as many as 182%. The greatest differences in the monthly evaporation totals calculated using formula (4,5) were noted in the same period. In November they reached 16% of the actual evaporation sum and in May 144%. The characteristic trait of the pattern of monthly evaporation totals is that the greatest differences occur at the beginning and towards the end of the season, the smallest differences being noted in the period June-September.

In the evaluation of evaporation from the water surface using empirical formulae the data from the nearest meteorological station are most frequently applied. Hence the question arises how these data can affect the obtained results. The question was answered using empirical Penman (2) and (4,5) and Davydov (3) formulae in the calculation of monthly evaporation totals from the water surface on the basis of data from the meteorological station of Biebrza lying 12 km of Lake Rajgrodzkie. The results were compared with the

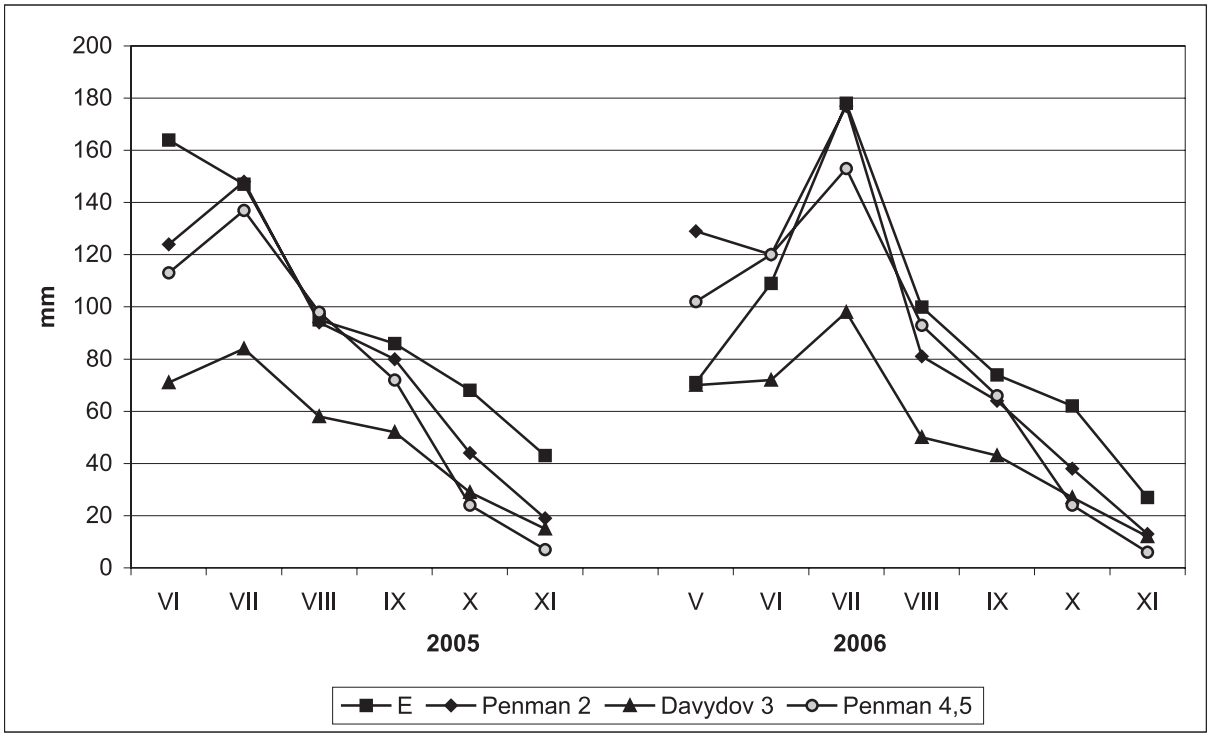

Fig. 1. Comparison of actual evaporation totals (E) from Lake Rajgrodzkie with evaporation totals from the water surface calculated using formulae (2), (3) and 4,5).

Table 1. Comparison of actual evaporation totals (E) from Lake Rajgrodzkie with evaporation totals from the water surface calculated using formulae (2), (3) and (4,5).

	E	Penman 2	% E	Davydov 3	% E	Penman 4,5	% E
VI. 2005	164	124	76	71	43	113	69
VII. 2005	147	148	101	84	57	137	93
VIII. 2005	95	94	99	58	61	98	103
IX. 2005	86	80	93	52	60	72	84
X. 2005	68	44	65	29	43	24	35
XI. 2005	43	19	44	15	35	7	16
VI-XI. 2005	**603**	**509**	**84**	**309**	**51**	**451**	**75**
V. 2006	71	129	182	70	99	102	144
VI. 2006	109	120	110	72	66	120	110
VII. 2006	178	177	99	98	55	153	86
VIII. 2006	100	81	81	50	50	93	93
IX. 2006	74	64	86	43	58	66	89
X. 2006	62	38	61	27	44	24	39
XI. 2006	27	13	48	12	44	6	22
V-XI. 2006	**621**	**622**	**100**	**372**	**60**	**564**	**91**

evaporation calculated on the basis of data from the raft (figs 2, 3, 4; Table 2).

The magnitude and pattern of monthly evaporation sums calculated using the Penman formula (2) on the basis of data from the land and from the lake show a distinct similarity (fig.2). The seasonal evaporation sums calculated using the data from the land were 20% lower in 2005 and 9% lower in 2006. The highest differences (-39%) were found in 2003 and the lowest (+2%) in June and July 2006.

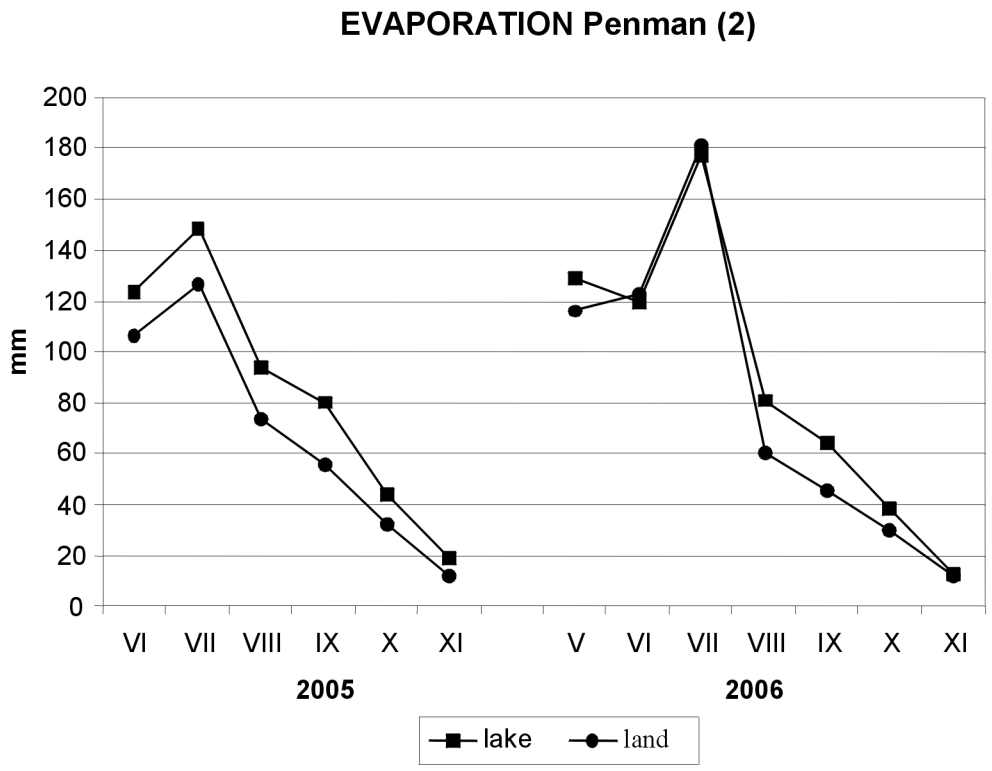

Fig. 2. Comparison of evaporation calculated using the Penman formula (2)

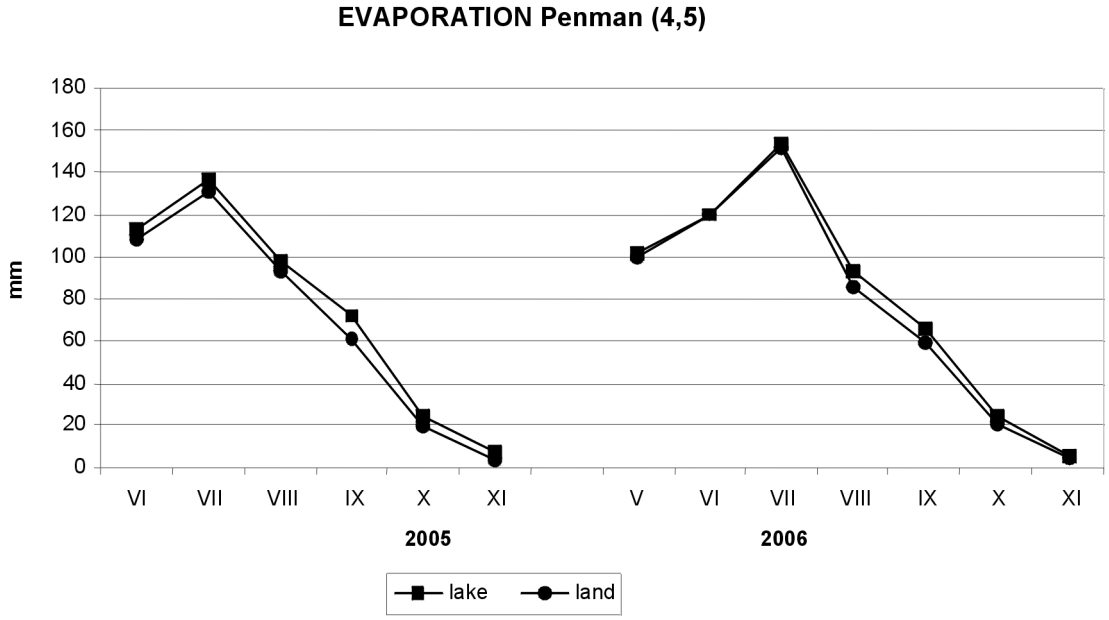

Fig. 3. Evaporation calculated using the Penman formula (4,5)

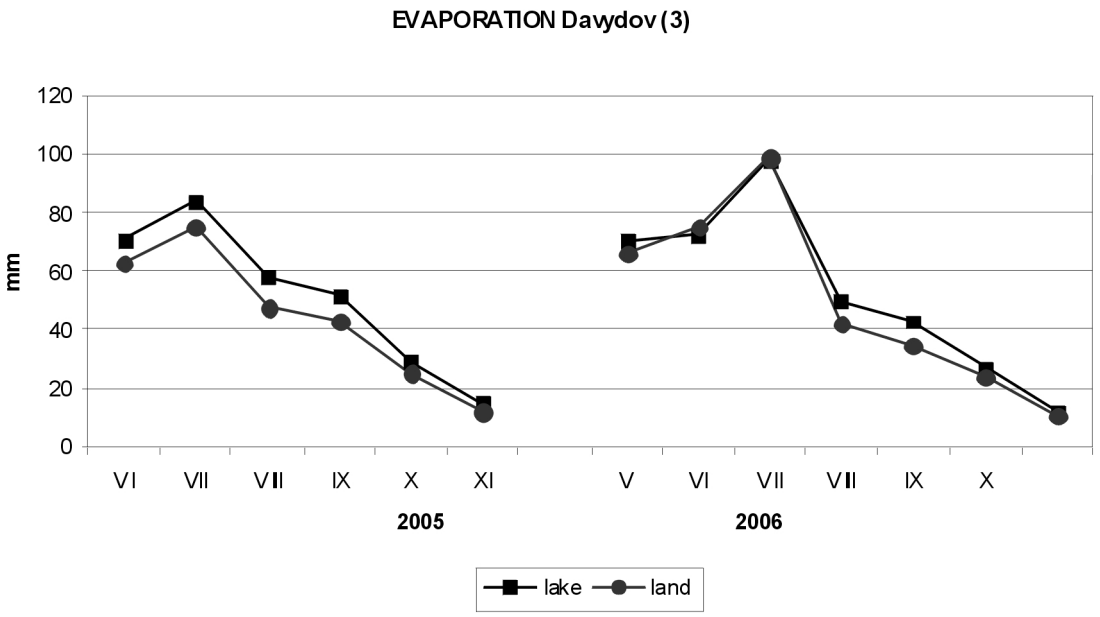

Fig. 4. Comparison of evaporation calculated using the Davydov formula (3)

Table 2. Comparison of actual evaporation totals (E) from Lake Rajgrodzkie with evaporation totals calculated using formulae (2), (3) and (4,5) for lake and land conditions

	E	Penman 2				Davydov 3				Penman 4, 5			
		Lake	%	Land	%	Lake	%	Land	%	Lake	%	Land	%
VI. 2005	164	124	76	106	65	71	43	63	38	113	69	108	66
VII. 2005	147	148	101	127	86	84	57	75	51	137	93	131	89
VIII. 2005	95	94	99	73	77	58	61	48	51	98	103	93	98
IX. 2005	86	80	93	56	65	52	60	43	50	72	84	61	71
X. 2005	68	44	65	32	47	29	43	25	37	24	35	19	28
XI. 2005	43	19	44	12	28	15	35	12	28	7	16	4	9
VI-XI. 2005	**603**	**509**	**84**	**406**	**67**	**309**	**51**	**266**	**44**	**451**	**75**	**416**	**69**
V. 2006	71	129	182	116	163	70	99	66	93	102	144	100	141
VI. 2006	109	120	110	123	113	72	66	75	69	120	110	120	110
VII. 2006	178	177	99	181	102	98	55	99	56	153	86	151	85
VIII. 2006	100	81	81	60	60	50	50	42	42	93	93	86	86
IX. 2006	74	64	86	46	62	43	58	35	47	66	89	59	80
X. 2006	62	38	61	30	48	27	44	24	39	24	39	20	32
XI. 2006	27	13	48	12	44	12	44	11	41	6	22	5	19
V-XI. 2006	**621**	**622**	**100**	**568**	**91**	**372**	**60**	**352**	**57**	**564**	**91**	**541**	**87**

Distinctly lesser effects of meteorological conditions on total evaporation from the water surface are observed if the potential evaporation is calculated using the Penman formula (4,5). In this case the values of monthly totals of evaporation were almost identical with the data obtained from the evapometric raft (Fig.3). The seasonal evaporation totals calculated from the land data were lower than the evaporation calculated on the basis of data from the raft by 8% in 2005 and by 4% in 2006. The greatest differences (-43%) appeared in November 2005. In June 2006 identical evaporation was recorded from the land data and from the raft.

The evaporation calculated using the Davydov formula distinctly differs from that calculated using two Penman formulae, however, similar differences are retained between the values calculated on the basis of data "from the land" and "from the lake" (Fig. 4). The seasonal sum of evaporation from the land was 14% lower in 2005 and 5% in 2006. The greatest differences (-20%) appeared in November 2005 and the smallest ones (+1%) in July 2006.

Recapitulation

The comparison of monthly totals of actual evaporation from the surface of Lake Rajgrodzkie and the monthly totals of evaporation from the water surface estimated using selected empirical formula shows that

1. the use of the Penman and Davydov empirical formulae considerably decreases monthly totals of evaporation from Lake Rajgrodzkie;

2. the results obtained with the Penman empirical formula (4,5) are as near as possible to direct measurements;

3. the use of meteorological elements derived from distant (land) measuring stations in the empirical formulae brings about further decreases in the results of calculations of evaporation.

Discussion

Analyses of the results obtained from the calculation of evaporation using three empirical formulae show that they are understated in relation to the actual evaporation. It seems that the Penman formulae for evaporation from the water surface (2) and for potential evaporation (4,5) give results as near as possible to the actual evaporation. Differences between the evaporation from the water surface and the potential evaporation are slight, confirming the opinion about the similarity of both evaporation kinds (Bac 1968).

The monthly totals of evaporation from the water calculated using the Davydov formula (2) distinctly differ from the results of measurements from the raft, showing that the Davydov method should not be used in the investigated region.

It is also worth noting that the evaporation from the water surface measured in the seasons of 2005 and 2006 exceeds 600 mm. The results of earlier studies in this area showed seasonal evaporation averages from the water surface at the level of 455 mm (Jurak 1970, 1976). The years 2005 and 2006 were characterized by an average precipitation total and the temperature higher by 0.2-0.3°C than the many years' average (1970-2002). It is difficult to say if an increase in temperature played such a significant role in the intensity of evaporation. It can be only confirmed by further studies.

Conclusions

The above considerations of the role of the selected methodology in the calculation of evaporation in the water balance of lakes show that

- empirical methods of calculating evaporation from the water surface give understated results in comparison with the actual evaporation;

- in the investigated region the calculation with the use of the Penman formulae (2) and (4,5) gives results approximating to the actual evaporation;

- (in the eastern part of the Mazurian Lakeland) actual evaporation from the water surface is 30% higher than the value so far given in the literature.

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