Changes in water resources in selected lakes in the middle and lower catchment of the River Warta

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Abstract: Lakes play a very important function in water retention, particularly in areas with strong water deficiency. Water resources in lakes determine the possibility of using them for different purposes, e.g. economic development (irrigation or drinking water, water supply for industry). With ongoing processes causing a reduction in lake capacity (shrinking and shallowing), it is necessary to investigate the scale and rate of decreasing lake resources, in terms of the economic and natural consequences of this process. The aim of the study was to test changes in water resources in lakes situated in the middle and lower River Warta catchment. Special attention was paid to lakes characterised by reduced water resources in order to identify factors contributing to this phenomenon. Our current studies of 127 lakes showed a 10% decrease in water resources over 50 years (1910-1960) in the analysed part of the catchment. Our results indicated that the predominant process causing the disappearance of lakes is shallowing. This factor should be monitored carefully to avoid further lake loss.

Key words: lake disappearance, shallowing, shrinking

Introduction

Lakes are a crucial link in the water cycle. One of the important roles of lakes is their water retention capabilities. This is very important in regions where water deficiency is serious and occurs more frequently. Water shortage often occurs due to improper management of the environment, e.g. drainage of wetlands, deforestation, etc.

In Europe, river regulation and agricultural use of rivers and lake floodplains have had a large impact on the dwindling of lakes (Müller et al. 1998; van Puijenbroek et al. 2004; Choiński and Ptak 2009). The disappearance of hydrodynamic gradients due to the construction of dykes, weirs and other flood defence measures or predominantly due to dams' and levees' constrictions caused the degradation of lakes. Changing land use in lake basins related to urbanisation and impermeabilisation, drainage of agricultural fields, river regulations and reduction in the size of active floodplains are the primary cause of increasing discharge quantities and they also enhance extreme flood events (Pfister et al. 2004; Anthéunis 2007). A large

amount of rainfall in lake basins supports massive discharge into lakes and sustains a strong basin effect on lake levels and water quality (Hu et al. 2007). Excluding eutrophication, which is recognised as the major factor driving lake disappearance, lakes in mountain areas show rapid filling due to natural processes such as avalanche occurrence (Choiński and Ptak 2009), water supply from glaciers or snow accumulation, and cyclical modifications in the evapotranspiration regime (Pasquini et al. 2008). In Poland, lake disappearance is most pronounced in agricultural areas. A good example of changes caused by intensive land use is seen in a large part of the Wielkopolsko-Kujawskie Lakeland.

Unfortunately, the water retention capacity of lakes changes due to the influence of such factors as shallowing and shrinking. Permanent interactions between these processes may, in the near future, prevent the use of lake water resources for economic purposes, i.e. irrigation, filling ponds. Continued lake use accompanied by simultaneous shrinkage of the water volume can accelerate the exhaustion of inviolable resources necessary for the lake functioning.

Most studies focusing on changes in water resources in Poland deal with the assessment of lake size (Majdanowski 1954; Mikulski 1965; Jańczak 1984; Choiński 1988) and are based on analyses of individual lakes or groups of several (a maximum of one dozen) lakes (Choiński 2002, 2007; Choiński and Ptak 2009; Ławniczak et al. 2011). Investigations and studies including a higher number of lakes are essential. Recognition of the major processes triggering lake disappearance and the rate of their loss is crucial for proper management and protection of lake ecosystems.

The aim of the study was to test changes in water resources in lakes situated in the middle and lower River Warta catchment. Special attention was paid to lakes characterised by reduced water resources in order to identify factors contributing to this phenomenon.

Material and methods

Comparative analyses were applied based on materials from the beginning of the 20th century (Schütze 1920; KJP 1954) and from the beginning of the 1960s (Choiński 2006). In total, 127 lakes from the middle and lower part of the Warta catchment were selected. Table 1 presents the surface area, volume and latitude of the studied lakes within two periods. The final number of chosen lakes depended on available data from both periods. The first sources of data came from investigations carried out by German researchers from 1904-1916 (Schütze 1920; KJP 1954). The second set of data came from the Institute of Inland Fisheries in Olsztyn and were based on investigations carried out in the 1950s and 1960s (Choiński 2006).

The database from the initial period of studies was designated here as 1910 and the database from the second period was designated as 1960.

Results

During the first study period (1910), total lake surface was 25304.6 ha (assumed as 100%) and the volume was estimated at 2310.9 hm³ (assumed as 100%). In the second study period, the lake surface amounted to 23736.0 ha and the volume was 2079.9 hm³. It is evident that during the period of 50 years the surface area of the studied lakes decreased by 6.2% and their volume by 10% (Fig.1).

Of the 127 lakes examined, water resource reduction was observed in 93 reservoirs (73.2% of the total number of lakes). The highest decrease in lake

Fig.1. Schematic diagram of direction of water resources reduction

capacity amounting to 47.8% and 44.6% was detected in Prostynia and Stępińskie lakes, respectively.

In comparison with the beginning of the 20th century, 19 lakes increased their retention by almost one fourth. The water capacity of 10 of the studied lakes did not change. In 24 lakes an increase in water resources was detected. The most significant increases in water resources was detected in Lake Piechiewo (over 150%) and Lake Małe (by 100%).

In total over 50 years, lake surface was reduced by 6.2% and volume by 10%. Analyses of water resources within groups of lakes based on surface area showed the most significant changes in the biggest lakes (100-500 ha) (Tab. 2). This group was represented by the highest number of lakes. The richest water resources were accumulated in the group of large lakes, where 30% of total water capacity was stored in four lakes. Unfortunately, all lakes from this group were characterised by a reduction in water resources of 9.9%.

Table 3 presents the number of lakes within categories of their surface and water resource changes. The highest number of lakes is found in the group of lakes in which surface area declined by 0-25%, which was accompanied by a similar simultaneous reduction in water resources. The next group of lakes includes the category characterised by a surface increase of 0-25%, accompanied by a decrease in their volume by the same range.

This group as well as the two following groups (25-50 and more than 50) indicate that changes in water resources are influenced significantly not only by apparent shrinking processes but also by shallowing.

Continuous supply of material flowing in from the lake catchment, as well as from outside, together with biomass produced in the reservoir itself, lead to a permanent "lifting" of the bottom and this consequently decreases the capacity of the lake. Table 4 gives examples of lakes where shallowing is responsible for decreased water resources.

Table 2. Changes in water resources within size classes of lakes

Size class [ha]		0-5	5-10	10-20	20-50	50-100	100-500	500-1000	>1000
number of lakes	With increasing water resources	-	3	3	2	3	12	1	-
	With decreasing water resources	-	-	5	21	18	40	5	4
	Without changes in water resources	1	1	1	6	-	1	-	-

Table 3. Number of lakes in groups based on changes in surface and water resources

Water resources changes [%]		Decreased		„0”	Increased		
Surface changes [%]		50-25	25-0		0-25	25-50	>50
Decreased	50-25	1	4	1	1	1	-
	25-0	12	52	6	9	3	1
„0”		1	3	-	1	-	-
Increased	0-25	5	14	3	5	2	1
	25-50	-	-	-	-	-	-
	>50	-	1	-	-	-	-

Table 4. Changes in lake capacity due to shallowing

Lake	1910		1960	
	Surface [ha]	Volume [hm ³]	Surface [ha]	Volume [hm ³]
Bochenek	4.5	0.2	4.5	0.17
Dołgie Wilk.	44.0	2.6	44.4	2.2
Dubie	110.0	12.3	112.0	8.1
Grylewskie	110.0	4.8	119.1	4.3
Kierskie Małe	34.0	0.5	34.0	0.47
Lipno	9.0	0.5	9.0	0.49
Łobez	45.0	2.9	45.5	2.5
Miejskie	67.0	6.7	68.7	6.5

The surface of the first three lakes in Table 4 did not change over almost 50 years but their volume decreased by 5.9%. During the studied period, the remaining lakes increased their area by 3.6%, although their capacity decreased by a total of 19.5%.

The shallowing occurred in entire basins and the rate of accumulation depended on sediment material, bank slope and dynamics of water in the lake. However, the most sensitive to the shallowing process are lake bays and shallow parts. A good example

Table 1. Changes in lake surface and water resource

No°	Lake name	1910°			1960°		
		Surface	Volume	Altitude	Surface	Volume	Altitude
		[ha]	[hm³]	[m a.s.l.]	[ha]	[hm³]	[m a.s.l.]
18.89	Białeckie	38.0	1.0	39.7	34.1	0.8	39.7
18.106	Białkowskie	153.0	13.3	83.1	145.9	14.0	83.1
33.1	Biezdruchowo	49.0	3.6	96.0	48.8	2.8	97.0
11.33	Biskupińskie	128.0	7.4	79.6	116.6	6.4	79.6
43.8	Bnińskie	254.0	11.2	65.5	225.9	9.5	65.5
29.44	Bobowickie	36.0	2.8	51.5	36.5	2.8	51.5
42.6	Bochenek	4.5	0.2	70.8	4.5	0.2	70.8
20.35	Brzeźno	part of Lake Włókna			24.3	0.4	74.2
32.13	Brzostek	6.0	0.2	92.0	6.0	0.3	92.0
53.66	Bucierz Wlk	154.0	20.8	98.0	150.2	15.9	98.5
43.2	Budzińskie	19.0	0.2	61.4	17.4	0.3	61.4
10.4	Budziszewskie	177.0	9.7	71.5	163.0	7.8	71.5
3.38	Bukowieckie	56.0	2.9	79.0	41.4	1.9	79.0
63.59	Bytyń	823.0	94.9	113.0	877.1	91.5	113.0
18.49	Chalinek	17.0	0.5	38.0	15.1	0.4	36.7
29.56	Chłop	225.0	19.8	53.7	227.8	20.5	53.7
3.3	Chodzieskie	126.0	4.4	54.2	115.6	3.5	54.2
18.103	Chrzypskie	323.0	18.9	44.9	304.3	18.6	44.9
54.4	Chudowo	40.0	4.8	100.0	41.5	4.0	99.7
45.34	Ciemino	264.0	20.5	142.0	241.7	14.3	142.0
35.1	Cięszęcino	115.0	16.6	155.0	102.2	13.7	154.2
29.3	Cisie	42.0	3.5	40.0	39.2	3.7	40.7
54.55	Czaplino	98.0	11.0	133.0	108.3	13.3	133.0
10.3	Czarne	24.0	1.3	72.0	27.8	1.9	72.0
47.13	Człuchowskie Wielkie	202.0	22.2	158.0	158.7	20.8	157.8
42.5	Dębno	25.0	1.9	71.0	25.1	1.7	71.3
54.61	Dolgie Wielkie	44.0	2.6	137.0	44.4	2.2	136.7
44.36	Drawsko	1862.0	357.0	128.0	1871.5	331.4	128.7
71.59	Dubie	110.0	12.3	77.0	112.0	8.1	77.3
10.15	Durowskie	161.0	13.5	78.1	143.7	11.3	78.1
18.2	Duże Dormowskie	30.0	1.6	71.3	27.0	1.6	-
11.36	Gadowskie	31.0	1.1	79.8	29.6	1.0	79.8
12.1	Gąsawskie	108.0	5.8	79.9	99.0	5.7	79.8
29.33	Głębokie	120.0	9.5	50.0	124.9	11.5	50.4
18.8	Gorzyńskie	81.0	11.4	44.6	76.2	13.1	-
3.37	Grylewskie	110.0	4.8	79.3	119.1	4.3	79.8
42.18	Jarosławskie	10.0	0.3	76.3	11.2	0.4	76.3
18.65	Jaroszewskie	96.0	12.5	39.0	92.2	13.0	38.3
32.11	Jerzyńskie	46.0	2.9	94.5	38.9	2.1	94.5
45.31	Juchowo	31.0	0.9	143.0	32.0	0.8	143.2
54.45	Kaleńskie	113.0	16.4	140.0	106.2	12.2	-
22.46	Kamienickie	284.0	25.0	85.6	232.5	20.3	85.6
44.12	Kamień	23.0	1.3	143.0	35.8	1.1	130.4
54.13	Kańsko	51.0	3.1	117.0	54.1	1.8	118.1
31.14	Kierskie	310.0	34.1	71.9	210.0	34.1	71.9
31.15	Kierskie Mł.	34.0	0.5	71.7	34.0	0.5	71.7
10.16	Kobyleckie	68.0	5.1	78.7	65.7	4.8	78.7
44.54	Komorze	492.0	62.0	131.0	416.7	49.3	131.1
43.7	Kórnickie	87.0	3.0	65.3	81.9	2.1	65.3
72.28	Krępa	29.1	1.6	75.0	19.4	1.0	72.5
54.28	Krosino	190.0	14.8	123.0	177.2	12.7	123.0
54.52	Krzemienko	18.0	1.6	140.0	17.3	1.2	140.1
54.47	Krzemno	138.0	20.7	140.0	138.8	21.2	140.0
18.66	Kwileckie	20.0	1.0	80.4	19.5	0.7	80.4
21.7	Lednica	364.0	25.3	109.8	339.1	24.3	109.8
42.8	Lipno	9.0	0.5	70.0	9.0	0.5	70.0
45.7	Lubicko Wielkie	188.0	11.0	130.0	170.7	11.6	130.3
54.1	Lubie	1485.0	203.0	95.0	1439.0	169.8	95.0
17.13	Lubikowskie	340.0	37.5	54.6	314.7	34.8	54.6
31.13	Lusowskie	148.0	11.8	79.6	121.9	10.4	79.6
18.71	Lutomskie	174.0	8.7	37.6	172.7	11.6	37.6
18.46	Ławickie	95.0	7.1	36.6	90.1	6.5	36.5
11.2	Łękańskie	88.0	1.4	84.8	85.2	1.3	84.8
43.12	Łękno	27.0	0.8	67.1	26.1	0.5	67.7
35.2	Łobez	45.0	2.9	154.0	45.5	2.5	154.2
42.11	Łódzko- Dym.	137.0	7.3	64.7	119.6	6.2	64.7
42.15	Małe	10.0	0.1	78.8	9.8	0.2	78.6

29.55	Miejskie	67.0	6.7	57.0	68.7	6.5	57.0
12.39	Mielno	203.0	5.9	75.3	179.0	3.7	75.0
22.43	Mogileńskie	86.0	3.4	89.9	77.0	2.5	89.9
44.13	Niecino	42.0	1.8	130.0	35.8	1.1	130.4
31.9	Niepruszewskie	248.0	7.6	77.8	242.3	7.5	75.8
12.2	Oćwieckie	151.0	15.7	81.9	142.7	12.9	81.9
53.80	Okra	82.0	4.3	103.0	50.5	3.8	103.2
80.48	Osiek	604.0	66.0	53.0	538.9	50.0	53.4
22.24	Ostrowickie	281.0	22.4	99.6	276.7	22.9	99.6
22.69	Ostrowskie	349.0	32.8	99.0	214.5	31.2	98.9
29.21	Paklicko Wielkie	229.0	19.5	65.0	196.0	15.8	65.0
54.42	Piasiecznik Wielkie	41.0	3.3	133.0	45.4	2.9	133.0
29.51	Piechiewo	17.0	0.5	51.3	18.0	1.3	54.5
45.27	Pile	933.0	137.0	130.0	980.1	115.1	130.1
18.9	Płytkie	13.0	0.3	72.2	11.5	0.4	-
22.20.	Popielewskie	313.0	41.3	96.0	308.5	38.2	96.0
34.4	Powidzkie	1200.0	140.0	98.7	1174.7	134.7	98.3
18.21	Proboszczowskie	17.0	0.5	34.0	15.0	0.5	33.0
62.55	Prostynia	57.0	2.3	81.0	57.7	1.2	80.2
18.50	Puntik	21.0	0.9	39.0	19.6	0.9	39.4
51.31	Raczyńskie	79.0	2.6	68.0	84.4	2.3	68.9
10.2	Rogoźno	136.0	5.2	69.5	125.8	3.8	69.7
42.13	Rosnowskie	43.0	1.5	81.3	34.2	1.3	81.3
12.36	Sadłogoszcz	57.0	0.7	75.2	43.0	0.6	75.2
44.26	Siecino	776.0	111.4	129.0	729.1	104.4	129.0
11.31	Skarbińskie	75.0	4.8	79.4	64.0	3.0	79.4
20.45	Skockie	79.0	2.8	72.7	77.1	2.1	72.7
34.1	Skorzęcinskie	748.0	43.9	104.0	637.7	35.1	104.0
11.37	Skrzynka	29.0	2.7	79.7	27.9	2.4	79.8
43.5	Skrzyńskie Duże	77.0	3.2	65.2	91.5	3.1	65.2
43.6	Skrzyńskie Małe	20.0	0.7	65.1	17.4	0.6	65.1
9.4	Somoleńskie	27.0	2.6	59.0	29.0	2.5	59.0
34.52	Stepińskie	45.0	5.6	139.0	36.7	3.1	140.1
20.44	Stęszewskie	106.0	4.0	94.7	78.4	3.2	94.7
17.22	Stołur	23.0	1.8	55.3	21.3	1.7	55.3
42.1	Strykowskie	372.0	16.7	73.0	305.3	13.6	73.7
3.1	Strzeleckie	18.0	0.6	64.3	16.0	0.5	65.2
32.1	Strzeszyńskie	32.0	2.7	76.6	32.0	2.7	76.6
32.3	Swarzędzkie	90.0	2.5	70.9	93.7	2.1	-
22.39	Szydłowskie	142.0	21.0	95.2	140.2	15.8	95.2
18.54	Śremskie	122.0	25.2	39.0	117.6	23.7	39.3
42.2	Tomickie	68.0	0.8	69.0	47.2	0.7	69.0
45.44	Trzeciecko	293.0	18.8	134.0	295.1	16.0	130.2
54.29	Wąsosze	308.0	8.5	125.0	326.4	11.3	124.1
11.32	Weneckie	151.0	7.6	79.6	131.7	6.0	80.0
10.7	Wiatrowskie	31.0	1.2	77.8	26.9	1.0	77.8
22.36	Wiecanowskie	345.0	11.0	91.3	300.0	9.4	91.3
34.11	Wielatowo	184.0	4.0	143.0	186.6	4.6	142.7
45.53	Wielimie	1830.0	50.0	133.0	1754.6	40.1	132.7
29.65	Wielkie	377.0	7.2	51.2	238.7	5.0	-
43.10	Wielkie Jezioro	72.0	2.5	66.4	60.3	1.8	66.0
42.3	Wielkowiejskie	35.0	0.6	70.9	35.0	0.6	70.9
34.14	Wierzchowo	772.0	67.6	139.0	731.0	70.2	139.5
66.37	Więcborskie	218.0	15.1	108.0	194.0	16.2	108.0
54.31	Wilczkowo	304.0	27.5	123.0	300.4	23.3	123.0
42.7	Witobelskie	106.0	3.6	64.8	105.0	5.5	64.8
20.28	Włókna	107.0	4.0	74.2	74.4	2.4	74.2
29.37	Wyszanowskie	33.0	1.0	59.0	28.9	0.8	59.0
44.47	Żerdno	192.0	29.5	128.0	205.0	31.2	128.5
4.8	Żnińskie Duże	458.0	32.5	78.7	431.6	29.4	78.0
11.30	Żnińskie Małe	165.0	4.3	78.9	135.1	3.0	78.9

Abbreviations

* numbers according to Choiński (2006)

** data from Schütze (1920), KJP (1954)

*** data IIF (Choiński 2006)

is Lake Skorzęcińskie (Fig. 2). The 5 m isobath “withdrew” significantly, particularly in the isolated parts of the lake (Fig. 2). Major changes were also observed in the deeper part of the reservoir. The area marked by the 10 m isobath decreased and was divided into three smaller parts. This process could have been caused by sediment slipping on steep slopes, characteristic for a ribbon lake. It was particularly observed along the

peninsula in the eastern part of the lake. A schematic diagram of this process is presented in Fig. 3. Over almost 50 years, the lake surface decreased by 14.8% and its capacity by 20.1%.

Chrzypskie Lake is characterised by a different kind of bottom surface change (Fig. 4). The shore slope was not as steep as in the previous example. The movement of deposited sediments occurred due to

Fig.2. Bathymetry changes to Lake Skorzęcińskie

Fig.3. Cross section in a) 1910, b) 1960 and c) imposition of both profiles

Fig.4. Bathymetry changes to Lake Chrzypskie

water transport properties, especially turbulent water movement induced by tributaries, wind, etc.

The role of tributaries in material loading and modelling processes of the lake bottom can be estimated on the basis of the 10 m isobath located in the southern part of the lake. This part of the lake was fragmented at the same level as the river inflow, with a simultaneous change in the outline of the area designated by this depth. However, the stable localisation of the 5 m isobath at the inflow of one of the tributaries is unclear, accompanied by simultaneous changes in further parts of the lake basin. These results indicated that river discharge reduced and lost its transport properties a significant distance from the inflow. In this part, intensive deposition of the transported material appeared. Lake Chrzypskie's surface decreased by 5.8% and its volume by 1.6% during the 50-year study period.

Conclusions

The analyses of water resources showed a very unfavourable reduction in water capacity in the catchment of the River Warta. The disappearance of lakes occurred as a result of two parallel processes: shallow-

ing and shrinking causing loss of water resources in the studied lakes over approximately 50 years by 10%.

The discussed processes of disappearance of the analysed lakes could have been caused by farming intensification and nutrient loading from the catchment area. During the last decade, fertiliser application increased by 34.3% in Wielkopolska Voivodeship (USP 2001, 2010). Choiński (2007) and Choiński and Ptak (2009) hypothesised that changes in lake areas may be caused by intensive land improvement, particularly done during the 70s.

Our results indicated that the observed increase in water resources in some lakes was accelerated by an increase in lake areas. Hydrotechnic activities, consisting of water raising by damming in natural lakes for the purposes of increasing water resources can be effective only in the short-term perspective. Processes leading to the "filling" of lakes with organic material occur permanently, particularly in the lowest part in the catchment. Furthermore, the transformation of semi-aquatic or terrestrial environments to aquatic ones, as the result of an increase in water level, may accelerate the process of erosion and deposition of organic matter in the lake basin.

One of the effective methods to increase water resources and reduce lake disappearance is sediment removal. However, this method is rarely used due to its high cost.

In order to reduce the rate of loss of water resources, it will be important to reduce nutrient loading to water bodies and to improve water quality in lakes and tributaries.

The obtained results indicated that one of the major processes causing lake disappearance is the invisible process of shallowing. This factor should be more strongly articulated in studies concerned with lake disappearance.

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