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PRELIMINARY ASSESSMENT OF AGRICULTURE INFLUENCE ON HEAVY METAL CONTENT IN BOTTOM SEDIMENTS OF SMALL WATER RESERVOIRS AND IN RUSHES

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Abstract

The main purpose of the paper was to determine the influence of catchment management on the bottom sediments quality of small water reservoirs as well as to determine toxic metal content in rushes. Samples of bottom sediments were collected in winter 2013 year, form 4 sediment layers (0-5, 5-10, 10-20 and 20-30 cm) at three points along the body of water. The 48 samples were collected. Soil material was prepared according to the procedures used in soil science, the analysis was performed for the fraction with a particle diameter of less than 1 mm. Plant samples from single species aggregations were randomly cut from 5 to 10 locations of 20-50 m^2 area. From these samples the average composite sample was prepared. The total content of such elements as Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn was determined by atomic absorption spectrometry (using the Thermo Scientific iCE 3000 series spectrometer) after prior digestion in the mixture (5:1) of concentrated acids HNO_3 (65%) and $HClO_4$ (60%). Total Hg content was determined by the AMA 254 analyzer. Between the small water reservoirs adjacent to the areas where organic farming is used, and the reservoirs adjacent to the areas with mineral fertilization there are statistically significant differences in the concentrations of such metals as nickel (layers: 0-5, 5-10, 10-20 and 0-30 cm), as well as cobalt, chromium and iron (in a layer 5-10 cm). It has been found that some plants accumulate higher amounts of heavy metals (average values). Based on obtained results it can be stated that rushes actively captures large amounts of elements reaching studied objects and thereby protect the surface water of the reservoirs from contamination.

Key words: agriculture, ecology, heavy metals, sediments, ponds

INTRODUCTION

Bottom sediments fulfill important role in the biogeochemical cycle of elements, they constitute the place of deposition and chemical transformations for numerous compounds penetrating to waters from the adjacent areas and create the living environment for aquatic organisms. Sediments and surface waters of small water reservoirs (also referred as ponds) located in agricultural areas are especially exposed to elevated supply of mineral substances, including heavy metals and nutrients (nitrogen and phosphorus). On the areas of farming activity the sources of contamination reaching the ponds are area-related. Chemical composition of sediments is associated to the effect of numerous factors, primarily the lithological structure of the catchment, soil type, terrain and catchment management (Tarnawski 2012). The natural content of heavy metals in soils does not threaten the ecosystems. However, the natural content of these metals is subjected to constant modifications due to human pressure, as pollution, fertilization, e.t.c. The greatest threat to small water reservoirs is the constantly progressing farming intensification. Heavy metals are supplied to waters through the surface runoff from the adjacent areas and with ground waters. As they are bioaccumulated in vegetation and aquatic organisms, heavy metals present in sediments and in the water constitute a threat to the flora and fauna of small water reservoirs. Heavy metals are especially dangerous in the aquatic environment due to their toxicity, durability and bioaccumulation. Lacustrine sediments are sensitive indicators of contamination, they act as a geosorbent and constitute the carrier of contaminants found in the aquatic environment (Fu *et al.* 2013; Bai *et al.* 2011; Caeiro *et al.* 2005; Suresh *et al.* 2012). Only a small amount of contaminants remains in the water and a considerable amount is deposited in bottom sediments due to adsorption, hydrolysis, co-precipitation (Gaur *et al.* 2005; Hau *et al.* 2013). Rush plants constitute an important element of ponds. Determination of their composition is important for the assessment of the environment status. Rush plants play important role in intercepting pollutants running off from fields and in the matter cycle of aquatic ecosystems (Falandysz *et al.* 1996, Szydłowski and Podlasińska 2014).

The conducted study aimed at determination of the influence of the catchment management type on concentrations of sediments from small water reservoirs (midfield ponds) in the Barlinek municipality and the content of heavy metals in rush plants.

MATERIALS AND METHODS

Characteristics of study objects

Four study objects were selected. The study objects are located in the West Pomeranian Voivodeship, Barlinek municipality near the Mostkowo township (Fig. 1). The small water reservoirs are adjacent to the areas of previous usage by a State Agricultural Farm (mineral and organic fertilization used). Currently, on the area surrounding the reservoirs no. 1 and 2 (52°59'54.24"N15° 3'17.95"E and 53° 0'4.52"N15° 3'39.96"E respectively) organic farming is applied (one organic farm). On the other hand, on the area adjacent to the reservoirs no. 3 and 4 (52°59'32.97"N15° 2'59.87"E and 52°59'26.76"N15° 2'45.66"E respectively) farming is carried out using rational mineral fertilization (NPK). The study objects are characterized by rushes typical of water bodies, i.e. common reed (*Phragmites australis* (Cav.) Trin. ex Steud), broadleaf cattail (*Typha latifolia* L.), sedges (*Carex spp*. L), common rush (*Juncus effusus* L.), yellow flag (*Iris pseudacorus* L.). In 2013 wheat was cultivated within the catchment of the no. 1 and 2 small water reservoir, whereas on the area adjacent to no. 3 and 4 water bodies rapeseed was grown.

Characteristics of sediment sample and vegetation collection and chemical analysis

A total of 54 samples (sediments and plants, respectively 48 and 6) were collected. Sediment samples were collected in winter 2013 from the layers: 0-5, 5-10, 10–20 and 20-30 cm, from three points along the water body. The obtained soil material was prepared following the procedures used in soil science, and the analyses were conducted for the particle fraction below 1 mm. From the separated areas of the pond banks vegetation samples were collected for chemical analyses. Vegetation samples of single species aggregates were obtained through their random cutting down from 5-10 places with the surface area from 20 to 50 m^2. From these samples average cumulative samples were formed, which were analyzed after drying and grinding. The total heavy metal content, i.e. Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn was determined using the Thermo Scientific iCE 3000 series atomic absorption spectrophotometer after prior mineralization of the sediments in a mixture (5:1) of concentrated acids HNO_3 (65%) and $HClO_4$ (60%). Hg content was determined using the AMA 254 analyzer. The obtained results were statistically elaborated using the Statistica 12.0 software. For the obtained results, the Shapiro-Wilk test of normality was used ($p \leq 0.05$), which confirmed the normality of the result distributions.

Figure 1. Location of midfield small water reservoirs (source: QGIS)

Table 1. Basic parameters characterizing the small water reservoirs

Object no.	Type of catchment management	Surface	
		Small water reservoirs	Waters
		ha	
1	Organic farming	3.24	0.27
2	Organic farming	11.73	1.59
3	Sustainable farming (with mineral fertilizers application)	0.19	0.06
4	Sustainable farming (with mineral fertilizers application)	0.13	0.05

RESULTS AND DISCUSSION

The obtained results allowed to determine that the highest concentrations of the tested trace elements were found in the samples from the middle portions of small water reservoirs. The highest concentration of examined elements characterized the pond no. 4 (Table 2).

The average (± standard deviation) heavy metal content in the tested sediments was 0.58±0.46 mg Cd·kg^{-1}; 4.38±2.71 mg Co·kg^{-1}; 20.35±19.98 mg Cr·kg^{-1}; 23.01±14.40 mg Cu·kg^{-1}; 10,514±6,575 mg Fe·kg^{-1}; 171.9±77.53 mg Mn·kg^{-1}; 11.82±7.61 mg Ni·kg^{-1}; 35.28±68.12 mg Pb·kg^{-1}; 97.5±90.3 mg Zn·kg^{-1} and 0.128±0.061 mg Hg·kg^{-1} (Table 2).

Table 2. The content of heavy metals [mg·kg^{-1}] in the bottom sediments of investigated small water reservoirs

No. of reservoir	Sampling site	Layer [cm]	Cd	Co	Cr	Cu	Hg	Mn	Ni	Pb	Zn	Fe
Organic farming catchment												
I	**bb***	0 – 5	0.91	2.62	9.42	20.00	0.157	166.6	5.89	25.94	37.0	13547
	bb*	5 – 10	0.93	2.98	9.69	20.11	0.153	142.0	6.68	29.83	31.2	1449
	bb*	10 – 20	0.99	3.35	9.65	23.71	0.124	141.3	7.48	26.45	20.9	1324
	bb*	20 – 30	0.66	3.42	15.47	34.22	0.103	124.8	11.45	8.59	38.0	1457
	ś**	0 – 5	1.13	3.36	10.78	24.44	0.142	158.8	6.83	27.68	37.6	1075
	ś**	5 – 10	1.07	3.61	13.10	28.80	0.133	164.5	9.22	22.34	37.9	1328
	ś**	10 – 20	0.84	5.49	16.95	34.36	0.104	159.1	13.48	17.15	58.8	15102
	ś**	20 – 30	0.72	3.05	11.87	48.71	0.047	84.3	7.23	16.04	304.5	8611
	b***	0 – 5	0.97	3.30	14.59	32.42	0.133	198.6	8.98	30.57	46.0	9668
	b***	5 – 10	0.91	3.06	18.74	45.17	0.107	159.1	11.17	13.69	57.7	11793
	b***	10 – 20	0.67	4.45	21.84	57.31	0.065	138.7	15.03	6.43	101.4	18650
	b***	20 – 30	0.07	11.52	54.45	43.71	0.028	491.8	33.45	15.47	1157	32769
II	**bb***	0 – 5	0.38	1.64	7.06	7.61	0.140	189.1	3.15	25.70	28.0	3155
	bb*	5 – 10	0.31	1.44	6.42	7.05	0.121	115.3	2.96	21.16	24.8	5852
	bb*	10 – 20	0.40	1.55	7.36	8.74	0.128	97.0	3.56	28.07	35.4	3864
	bb*	20 – 30	0.64	1.76	8.03	9.85	0.139	79.2	3.49	27.19	38.5	2684
	ś**	0 – 5	0.48	2.66	8.05	11.35	0.132	397.2	4.61	28.03	43.1	4867
	ś**	5 – 10	0.53	3.08	8.87	13.26	0.184	400.9	5.78	24.65	78.8	10084
	ś**	10 – 20	0.65	2.41	8.86	11.21	0.176	401.2	4.09	29.48	58.5	5698
	ś**	20 – 30	0.67	2.45	9.07	11.15	0.153	393.7	4.13	30.33	48.9	4847
	b***	0 – 5	0.34	3.58	13.73	10.34	0.096	78.6	9.36	15.99	37.1	8447
	b***	5 – 10	0.21	2.85	11.55	6.78	0.068	49.4	9.09	8.43	21.4	7408
	b***	10 – 20	0.15	2.51	10.17	6.62	0.053	51.7	6.48	10.21	19.5	18106
	b***	20 – 30	0.00	2.06	9.66	5.60	0.049	47.3	5.18	3.45	16.6	4730

No. of reservoir	Sampling site	Layer [cm]	Cd	Co	Cr	Cu	Hg	Mn	Ni	Pb	Zn	Fe
Sustainable farming catchment												
III	**bb***	0 – 5	0.02	1.97	8.10	5.97	0.186	51.9	4.93	3.12	14.6	4557
	bb*	5 – 10	0.00	2.48	9.65	6.24	0.205	57.7	5.55	7.14	15.7	6322
	bb*	10 – 20	0.16	2.54	16.72	8.55	0.173	75.7	12.01	12.45	21.7	5746
	bb*	20 – 30	0.22	6.64	23.85	19.12	0.138	185.7	16.01	33.42	53.1	15318
	ś**	0 – 5	0.21	8.23	39.43	20.30	0.122	195.6	28.78	30.41	69.0	18076
	ś**	5 – 10	0.30	7.82	22.96	19.88	0.111	177.5	18.20	30.44	69.3	19677
	ś**	10 – 20	0.28	7.50	26.48	19.91	0.123	188.9	18.47	31.81	75.6	20012
	ś**	20 – 30	1.04	13.72	62.54	43.32	0.111	389.3	40.62	77.14	173.4	34022
	b***	0 – 5	0.38	4.28	18.27	17.48	0.212	172.4	11.63	29.13	55.6	11198
	b***	5 – 10	0.38	4.62	16.32	16.45	0.168	164.3	11.09	22.14	50.0	10373
	b***	10 – 20	0.43	3.76	14.53	14.84	0.188	155.7	9.88	17.89	43.0	9370
	b***	20 – 30	0.17	5.64	21.51	18.46	0.151	205.8	12.91	19.29	57.1	13255
IV	**bb***	0 – 5	0.97	4.30	94.90	33.22	0.098	158.9	15.31	339.81	369.0	11550
	bb*	5 – 10	0.86	4.28	29.65	33.38	0.112	182.2	12.57	104.51	204.9	9869
	bb*	10 – 20	1.99	9.19	64.47	75.92	0.151	293.6	23.36	94.20	304.7	22322
	bb*	20 – 30	0.75	4.53	25.79	27.44	0.172	112.8	13.84	70.41	151.6	11045
	ś**	0 – 5	1.13	6.21	17.96	29.72	0.328	146.9	14.33	44.45	114.4	12320
	ś**	5 – 10	0.80	5.36	19.70	19.93	0.191	125.4	14.60	49.11	72.5	11746
	ś**	10 – 20	0.96	8.79	28.77	26.20	0.114	252.2	21.31	80.68	97.4	15441
	ś**	20 – 30	0.68	4.50	22.54	25.31	0.099	105.8	13.03	44.91	143.6	9734
	b***	0 – 5	0.28	3.67	16.01	12.88	0.084	80.7	11.46	14.75	36.6	7412
	b***	5 – 10	0.15	6.34	31.16	36.49	0.070	172.3	19.43	34.24	62.2	15300
	b***	10 – 20	0.41	3.30	14.36	22.88	0.057	96.1	10.15	8.94	25.9	7108
	b***	20 – 30	0.60	2.57	15.64	28.27	0.043	75.3	9.34	0.32	21.8	6397

Explanations: * bb – side edge from the largest declines in the area around the reservoir; ** ś – middle point of reservoir; *** b – side edge of the smallest declines in the area around the reservoir;

The obtained results were compared to the results provided by Baran and Tarnowski (2013), Bojakowska and Sokołowska (1996), Szafran (2003) and Szydłowski and Podlasińska (2016). Those scientists examined water reservoirs whose catchments comprise areas with farming activities (with small number of craft enterprises), a industrial catchment and a typical farming activity catchments. A comparison of the results provided by the above mentioned authors enables to discover that the highest cadmium concentration determined in the present study (1.99 $mg \cdot kg^{-1}$ in samples from ponds no. 2 and 3) was similar to the results obtained in the study of Szafran (2003) (1.83 $mg \cdot kg^{-1}$), but was about

1.5 times higher than that determined in the study of Baran and Tarnawski (2013) (1.3 mg·kg^{-1}) and approximately 1.5 times lower than in the study of Bojakowska and Sokołowska (1996), who provide the value of 2.4 mg·kg^{-1} for the sediments of a small water reservoir. The maximum chromium, copper, nickel, lead concentration determined in the present study was higher than in the samples analyzed by the above mentioned authors (Bojakowska and Sokołowska 1996; Szafran 2003; Baran and Tarnawski 2013). In particular, the maximum lead concentration (339.81mg·kg^{-1}) determined in the 0-5 cm layer of the pond no. 4 in the intensely used catchment was three times higher than the value stated by Bojakowska and Sokołowska (1996) (118 mg·kg^{-1}), about fifteen times higher than the values provided by Baran and Tarnawski (2013) (21.6 mg·kg^{-1}), about six times higher than the value determined by Szafran (2003) (56.52 mg·kg^{-1}) and about seven times higher than in the study of Szydłowski and Podlasińska (2016). The maximum zinc concentration (369.01mg·kg^{-1}) in the surface layer (0-5) cm of the pond no. 4 (catchment used by sustainable farming with NPK mineral fertilization) was two times higher than the results of Baran and Tarnawski (2013). On the other hand, the maximum zinc concentration of the present study (369.01 mg·kg^{-1}) was approximately three times lower than the maximum concentration of this element in the sediments (1070 mg· kg^{-1}) provided by Bojakowska and Sokołowska (1996) for the reservoir located in the catchment with greater industrial impact than the present study area. However, this value was similar to the maximum zinc concentration in the study of Szydłowski and Podlasińska (2016). Moreover, the maximum mercury concentration (0.52 mg·kg^{-1}) provided by Bojakowska and Sokołowska (1996) was approximately 1.5 higher than the maximum concentration value of this element obtained in the present study (0.328 mg·kg^{-1}).

Table 3 shows concentrations of the tested elements in the sediments of ponds located in the areas used by sustainable farming (using NPK mineral fertilizers) and organic farming, expressed as mean values from the entire tested layer (0-30 cm), depending on the location of sample collection. Table 4 presents mean values of heavy metal concentrations for different layer of sample collection.

In order to determine whether the sample collection site influences the content of heavy metals in the sediments, mean heavy metal contents in the entire tested profile (layer 0-30 cm) of the examined ponds were calculated for 3 collection points (bb*, ś** and b***) – the results are presented in Table 3. The obtained results indicate different means of metal accumulation depending on the location of sample collection demonstrated by decreasing series of heavy metal content in bottom sediments for the catchments used by organic farming: Cd, Fe, Pb ś>bb>b; Co Cr, Cu, Ni b>ś>bb; Mn b>bb>ś; Zn ś>b>bb and Hg bb>ś>b for pond no. 1 and Cd, Cu, Mn, Zn, Hg ś>bb>b; Co, Fe, Ni b>ś>bb and Cr b>ś>bb for pond no. 2. In the case of ponds located in the catchment used by sustainable farming (NPK fertilization), these series exhibit lower variation and assume the following form: Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn ś>b>bb; Hg b>bb>ś;

Pb ś>b>bb for pond no. 3 and Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn bb>ś>b and Hg ś>bb>b for pond no. 4 (Table 3).

In general, in the cases of ponds no. 1 and 2 it can be stated that the highest mean concentrations for the entire tested sediment profile occurred in the middle part of the water reservoirs and at the bank from the side of the lowest terrain gradient around the reservoir, whereas in the cases of ponds 3 and 4 – in the middle portion of reservoir and at the bank from the side of the greatest terrain gradients around the reservoir.

Reason for such distribution of concentrations of the tested elements may be their binding by the finest fractions of sediments and sedimentation in the deepest point of the ponds, which for each of the tested reservoirs could be located in a different point.

The obtained results indicate that the highest concentrations of the analyzed heavy metals in the ponds located in the catchments with organic farming were found primarily in the layer 20-30 cm (Table 4). On the other hand, in the ponds located within the catchment where sustainable farming is applied, the highest concentrations of heavy metals were found primarily in the layer 0-5 cm and also (less frequently) in the 20-30 cm layer (Table 4). This may indicate that in the previous years more mineral substances reached the catchment of the ponds 1 and 2 and after the shift to new type of activity (organic farming) the influx of those substances was decreased. In the case of ponds 3 and 4 (sustainable farming) this influx continued (Table 4).

Table 3. Average concentrations of heavy metals [$mg \cdot kg^{-1}$] in bottom sediments samples (0-30 cm) of small water reservoirs, depending on the place of sampling

Heavy metals	Reservoir no. 1			Reservoir no. 2			Reservoir no. 3			Reservoir no. 4		
	Organic farming						Sustainable farming					
	bb*	ś**	b***	bb*	ś**	b***	bb*	ś**	b***	bb*	ś**	b***
Cd	0.87	0.94	0.66	0.43	0.58	0.17	0.10	0.46	0.34	1.14	0.89	0.36
Co	3.09	3.88	5.58	1.60	2.65	2.75	3.41	9.32	4.58	5.57	6.22	3.97
Cr	11.06	13.17	27.40	7.22	8.71	11.28	14.58	37.85	17.66	53.70	22.24	19.29
Cu	24.51	34.08	44.65	8.31	11.74	7.33	9.97	25.85	16.81	42.49	25.29	25.13
Fe	4444	6529	1822	3888	6373	9672	7985	22946	11049	13696	12310	9054
Mn	143.67	141.66	247.06	120.12	398.24	56.75	92.75	237.81	174.57	186.88	157.57	106.10
Ni	7.87	9.19	17.16	3.29	4.65	7.53	9.62	26.52	11.37	16.27	15.82	12.59
Pb	22.70	20.80	16.54	25.53	28.12	9.52	14.03	42.45	22.11	152.23	54.79	14.56
Zn	31.79	109.67	80.20	31.67	57.31	23.65	26.26	96.84	51.41	257.53	106.97	36.64
Hg	0.134	0.107	0.083	0.132	0.161	0.066	0.176	0.117	0.180	0.133	0.183	0.064

Explanations: like under Table 1.

Table 4. Average concentrations of heavy metals [mg·kg^{-1}] from different sampling place and catchment use depending on the sediments sampling depth

Layer [cm]	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Hg
Organic farming catchment										
0 – 5 cm	0.70	2.86	10.60	17.69	6793	198.14	6.47	25.65	38.12	0.133
5 – 10 cm	0.66	2.84	11.40	20.19	6319	171.84	7.48	20.02	41.95	0.128
10 – 20 cm	0.62	3.29	12.47	23.66	10457	164.84	8.36	19.63	49.09	0.108
20 – 30 cm	0.46	4.04	18.09	25.54	9183	203.51	10.82	16.84	93.69	0.087
Sustainable farming (with mineral fertilizers application) catchment										
0 – 5 cm	0.50	4.78	32.44	19.93	10852	134.39	14.41	76.94	109.86	0.172
5 – 10 cm	0.42	5.15	21.57	22.06	12214	146.57	13.57	41.26	79.09	0.143
10 – 20 cm	0.70	5.85	27.56	28.05	13332	177.03	15.86	41.00	94.71	0.134
20 – 30 cm	0.58	6.27	28.64	26.99	14961	179.13	17.62	40.92	100.10	0.119

Table 5. The significance of variation of the heavy metal concentrations in sediments in small reservoirs located in differently used basins (organic and intensive farming)

Heavy metals	**Type of variability – layers**				
	0–5 cm	**5–10 cm**	**10–20 cm**	**20–30 cm**	**0-30 cm**
Cd	n.s.	n.s.	n.s.	n.s.	n.s.
Co	n.s.	*	n.s.	n.s.	*
Cr	n.s.	*	n.s.	n.s.	*
Cu	n.s.	n.s.	n.s.	n.s.	n.s.
Fe	n.s.	*	n.s.	n.s.	*
Mn	n.s.	n.s.	n.s.	n.s.	n.s.
Ni	*	*	*	n.s.	*
Pb	n.s.	n.s.	n.s.	n.s.	*
Zn	n.s.	n.s.	n.s.	n.s.	n.s.
Hg	n.s.	n.s.	n.s.	n.s.	n.s.

Explanation: * – significance at the level of $p \leq 0.05$; n.s. – not significant

Statistical analysis demonstrated statistically significant differences (Tukey's test $p \leq 0.05$) for individual metals between the ponds adjacent to the areas with organic farming and the ponds adjacent to the areas fertilized with mineral nutrients in the following layers: in the 0-5 cm layer for nickel, in the 5-10 cm layer for cobalt, chromium, iron and nickel, and in the 10-20 cm layer for nickel (Table 5). On the other hand, no statistically significant differences were determined in the 20-30 cm layer. A comparison of the mean values of the tested metals concentrations in the profiles of both tested pond types gives out statistically significant differences for nickel, cobalt, chromium, iron and lead (Table 5).

The calculated variation coefficients for mean concentrations of the analyzed metals (Table 6) for the ponds located in catchments with organic farming remained in the range from 37.5% to 104.7%. For the ponds in the catchments with sustainable agriculture those coefficients were characterized by a wider range (43.2%-136.1%). The calculated coefficients are considerably higher (from 12% to 31%) than those provided by Baran and Tarnawski (2013) for the sediments of the pond located in the area with farming activity (with a low number of craft enterprises). Values of the variation coefficient of over 50% indicate anthropogenic source of heavy metals (Baran and Tarnawski 2013).

Table 6. Variation coefficients [%] of average metal content in the sediments of differently used catchments of small water reservoirs

Type of catchment manangement	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Hg
Organic	53.4	60.9	73.1	71.0	90.5	70.4	75.8	41.8	104.7	37.5
Sustainable	83.2	49.1	72.5	59.4	51.2	48.7	49.5	136.1	94.1	43.2

Rush plants constitute a typical element of water reservoirs. Their occurrence depends on habitat conditions. Moreover, they are also considered to be sensitive indicators of the state of the environment, as they constitute the buffering zone of ponds. Aquatic plants accumulate large quantities of pollutants originating from the surface runoffs to ponds (Stępień and Pawluczuk 2011; Wesołowski and Brysiewicz 2014; Wesołowski *et al.* 2011). The tested ponds contain typical rush vegetation of small water reservoirs. On the basis of the higher mean concentrations of heavy metals determined for certain plants it can be stated that rush vegetation actively captures large amounts of substances reaching the test objects (Table 7). This fact is best demonstrated by the broadleaf cattail (for nickel) and common reed (for manganese). Also, similar values of the selected heavy metals concentrations were determined in the rush vegetation of the ponds no. 1 and 2 for chromium, manganese and nickel. The accumulation of cobalt, cadmium, iron, zinc, lead in rush vegetation was at much lower level than in the bottom sediment samples of the analyzed midfield ponds. Despite the determined lower concentrations of heavy metals in the rush vegetation it can be stated that rushes constitute a certain ecotone inhibiting the influx of contaminants.

Wojtkowska (2014) presents similar results for rush plants stems for Zn and Cd from Zegrzyńskie lake as obtained in our research, but up to 10 times higher for Pb. Wesołowski *et al.* (2011) for common red and broadleaf cattail for Starzyc lake present similar values for Mn and up to 1.5-1.9 times higher for Zn in comparison to results presented in Table 7.

The obtained results are also considerably lower for Zn and Pb (up to 2.8 and 140 times, respectively) than those provided by Świerk and Szpakowska (2009) for rush vegetation water reservoirs form Poznań city area.

Table 7. Average concentrations of heavy metals in rushes and bottom sediments of examined reservoirs [mg·kg^{-1}]

Type of reservoir	Cd	Co	Cr	Fe	Mn	Ni	Pb	Zn
Plants – reservoir no. 1 and 2	**Common reed**							
	*	*	3.84	116.82	88.55	7.86	0.50	12.73
	Broadleaf cattail							
	0.15	0.04	7.61	104.71	158.25	12.22	*	13.07
Bottom sediments – reservoir no. 1 and 2	0.61	3.26	13.14	8188.15	184.58	8.28	20.54	55.71
Plants – reservoir no. 3 and 4	**Common reed**							
	0.10	0.04	4.31	228.54	210.1	19.54	0.21	19.92
	Broadleaf cattail							
	0.12	*	3.61	318.37	121.68	18.48	0.10	13.27
Bottom sediments – reservoir no. 3 and 4	0.55	5.51	27.55	12840.36	159.28	15.37	50.03	95.94

Explanation: * – below the determining level

CONCLUSIONS

1. The highest mean concentrations of metals in the entire tested profile of sediments were most common in the middle part of the water reservoir and at the bank from the side of the lowest terrain gradients around the pond no. 1 and 2, and in the case of the ponds no. 3 and 4 in the middle of the water reservoir and at the bank from the greatest terrain gradients around the water reservoir.
2. Statistically significant differences in metal concentrations occur between the ponds adjacent to the areas with organic farming and the

ponds surrounded by the areas fertilized with mineral nutrients: for nickel (layers 0-5, 5-10, 10-20 and 0-30 cm) and cobalt, chromium, iron (in the layer 5-10 cm).

3. The higher mean concentrations of heavy metals determined in certain rush plants indicate that vegetation actively absorbs large amounts of the substances reaching the tested objects, thus preventing penetration of contaminants to the surface waters of these water bodies.

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