Water quality and the assessment of anthropogenic pollution in the sediments of the Elbe River oxbow lakes

Lucie Beranová, Dagmar Chalupová

Abstrakt

Tato práce je zaměřena na zhodnocení kvality vody a antropogenního znečištění sedimentů ve starých ramenech Kozelská tůň a Vrť středního toku Labe. Stará říční ramena jsou významnými ekosystémy, ve kterých se může ukládat velké množství znečištěného materiálu. Tato kontaminace může pocházet z průmyslových zdrojů znečištění především z 2. pol. 20.století. Fluviální jezera také dokladují změny trasy koryta řeky a přispívají ke zvýšení stability říčního ekosystému. Výzkum Kozelské tůně byl zvolen především kvůli poloze tohoto jezera, které se nachází v blízkosti areálu Spolana Neratovice, a.s., která v minulosti představovala největší zdroj labského znečištění.

Tento výzkum zahrnoval batymetrické měření a měsíční analýzy chemických a fyzikálních parametrů vody v období od prosince 2016 do listopadu 2017. Okrajovou část práce představovala také mikroskopická analýza zooplanktonu.

Další část výzkumu zahrnovala stanovení koncentrace kovů a arsenu v sedimentech ve frakci 20 µm. K výluhu sedimentů byl kromě rozkladu lučavkou královskou použit i celkový rozklad.

Hodnocení kvality povrchové vody v jezerech prokázalo zvýšené koncentrace $N\text{-}NO_3$. Obsah $N\text{-}NH_4$ ve vodě byl v Kozelské tůni i v jezeře Vrť nejvyšší ze všech porovnávaných fluviálních jezer Polabí. Z mikroskopické analýzy planktonu vyplynulo, že v jezerech se nachází převážně druhy, které se běžně vyskytují v eutrofních vodách.

Z hlediska kontaminace sedimentů byly nejvyšší koncentrace stanovovaných prvků zjištěny především v Kozelské tůni, což potvrdilo hypotézu o šíření průmyslové kontaminace z blízkých zdrojů znečištění (Spolana, a.s. v Neratovicích) při povodni pravděpodobně i proti proudu řeky, jak bylo zaznamenáno např. za povodně v roce 2002.

Naopak sedimenty jezera Vrť byly kontaminovány méně. Z hlediska kontaminace sedimentů byla nejvyšší míra znečištění zaznamenána v případě stříbra a kadmia. Jak výzkum prokázal, kontaminované sedimenty fluviálních jezer představují v řadě lokalit v Polabí staré antropogenní zátěže, které mohou být během povodní remobilizovány a kontaminovaný materiál tak může představovat sekundární zdroj znečištění.

Klíčová slova: kvalita vody, subaquatické sedimenty, řeka Labe, fluviální jezera
Key words: water quality, subaquatic sediments, the Elbe River, oxbow lakes

Anotace

This research is focused on asseessing the water and sediment quality in oxbow lakes Vrť and Lake Kozelská in the middle course of the Elbe River. This work includes water sampling to analyse chemical and physical parameters of water, alanalyses of zooplankton in water and also sediment sampling to determine concentration of heavy metals and As in the sediments.
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Tento výzkum je zaměřený na zhodnocení kvality vody a sedimentů ve fluviálních jezerech Vrť a Kozelská tůň ve středním toku řeky Labe. Práce zahrnovala odběr vody k následné analýze chemických a fyzikálních parametrů vody a určení druhů zooplanktonu. Dále byl proveden odběr sedimentů a determinace koncentrací těžkých kovů a As v sedimentech.

1 Introduction

It is widely accepted that oxbow lakes are extremely significant ecosystems. Besides being the home of a variety of protected species, they increase retention potential and thus play a very important role in flood protection. Oxbow lakes also represent an area in the catchment where a lot of drifted material settles. Therefore, they are also a source of information about historical pollution, which has increased significantly in the Elbe River catchment over the second half of the 20th century.

Its water quality worsened significantly during the second half of the 20th century due to an overuse of fertilizers and a lack of industrial waste water treatment. However, it is still possible to find several protected areas whose preserved oxbow lakes still possess well-functioning ecosystems. In recent years, water and sediment quality of oxbow lakes in the Czech Republic was studies e.g. by Janský (2005), Chalupová (2007), and Havlíková (2011), who was focused on the development of water quality in Vrť - an oxbow lake that is a part of this study. However, these research works covered only some areas of the Elbe River floodplain. Many oxbow lakes have not been surveyed yet, for instance, Lake Kozelská situated in close proximity to the chemical factory Spolana in Neratovice, which used to be the biggest source of pollution of the Elbe River. In this paper I have focused on water quality and assessing anthropogenic pollution in the sediments. The research included bathymetric measurements, monthly analysis of chemical and physical parameters of water and analysis of zooplankton. Determination of metal and arsenic concentrations in sediments were carried out too. The results of the research were compared to previous studies of other oxbow lakes in the region to describe the anthropogenic pollution spread in the Elbe River floodplain.

1.1 Lake Kozelská

Lake Kozelská is located on the right bank of the river between 851,9 and 851,1 km close to Mlékojedy, which is situated in Neratovice district. The lake is connected with the river by small canals. The depths of this lake are shown in Figure 1.

During communist regime, adding of permanganate and liming on ice cover of the lake was applied. At this time, the subaquatic sediments were dredged, so the bottom of the lake was cleaned.

Canal connecting the lake with the river is surrounded by agriculture fields.

Figure 1: Bathymetric map of Lake Kozelská (left) and sampling in January (right)

1.2 Vrť

Lake Vrť is located on the left bank of the river between 881,7 and 881,2 river km in Semice, which is situated in Nymburk district. The lake is connected with the river at 881,2 km. Figure 2 shows bathymetric map with depths of Vrť and view of this lake in August.

Lake Vrť borders with natural protected area Vrť. Lake is surrounded by pine trees and agriculture fields. During communist regime, liming on ice cover was applied in the lake (Havlíková, 2011).

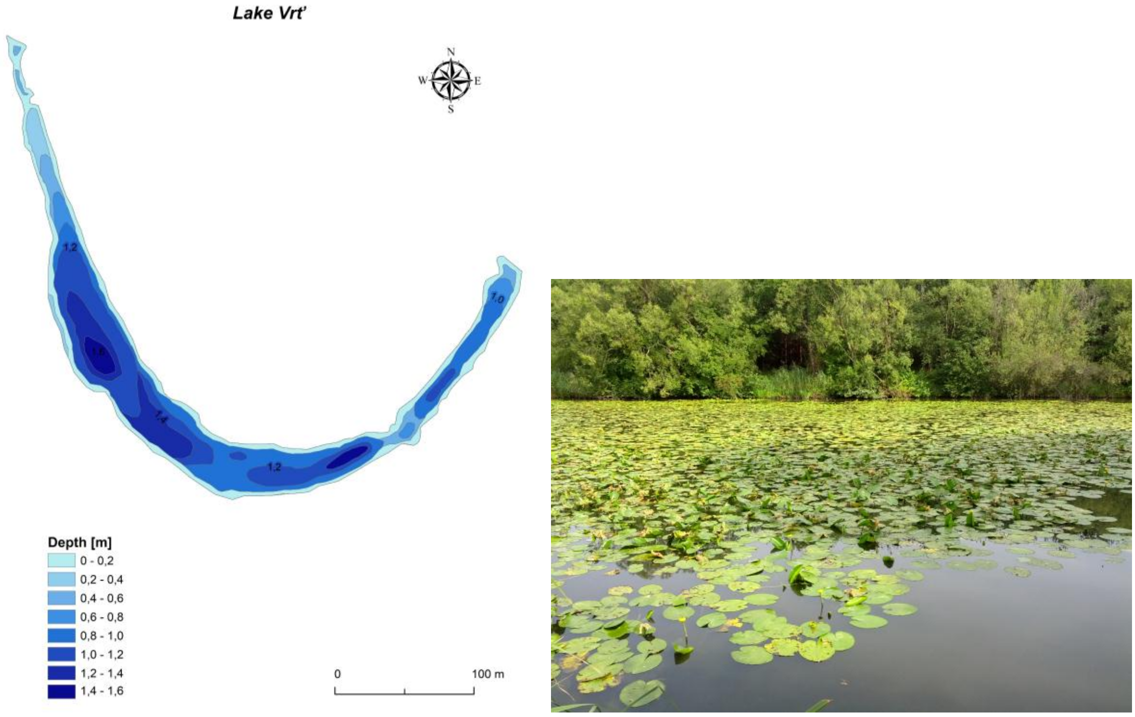

Figure 2: Batyhmetric map of Vrť (left) and lake in August (right)

2 Materials and Methods

2.1 Water quality

Surface water samples in both lakes were collected on 8th December 2016, 26th January, 9th March, 20^{t}h April, 25th May, 10th July, 24th August, 9th October, and 13th November 2017.

The samples were collected from the same sampling site approximately 1 m from the lake banks about 10 cm below water surface. PET bottles and glass samplers for BOD determination were used. During the winter, the surface of both lakes had an ice cover, for that reason, an 1m^2 holes were cut to make the sampling possible.

Measurements in Lake Kozelská were made at two different sites to get representative values. The result was calculated as a mean value from both sites. The sampling sites of Lake Vrť and Lake Kozelská are shown in Figure 3.

Figure 3:Sampling sites of water in Lake Kozelská (left) and Vrť (right)

Water temperature, dissolved oxygen, pH and conductivity were measured in the field by the multiparametric probe HQ40D Hach-Lange.

Other determined parameters as chemical oxygen demand (COD_{Mn}), biochemical oxygen demand (BOD_5), ammoniacal nitrogen ($N\text{-}NH_4$), nitrite nitrogen ($N\text{-}NO_2$), nitrate nitrogen ($N\text{-}NO_3$), orthophosphate phosphorus ($P\text{-}PO_4$), chlorides (Cl^-), alkalinity, calcium (Ca), iron (Fe), manganese (Mn) and water hardness were tested in the laboratory of The Institute for Environmental Studies at Charles University.

2.2 Zooplankton

Zooplankton samples were collected from both lakes on 24th August and on 9th October 2017. A plankton net of 40 µm mesh size was used for sampling. Samples were taken in the distance of 2 m from the lake bank by horizontal movements, then fixed with 80% ethanol, and kept in 100 mL bottles.

Measurements in Lake Kozelská were made on two different sites to get representative values. The result of species abundance value was calculated as a mean of both measurements. The sampling sites of Lake Vrť and Lake Kozelská are the same as sampling sites of water to chemical analysis.

Samples were observed using the microscope Olympus CX41 with 200x magnification according to the laboratory methods by doc. RNDr. Jana Říhová Ambrožová, Ph.D. (Department of Water Technology and Environmental Engineering UCT Prague) and ČSN 75 7712.

In the case of zooplankton, number of species was determined. Because of using this semi-quantitative method, the relative abundance of species was calculated. Resulting abundance represents a content of plankton species only in the collected samples, not in the lake.

2.3 Sediments

Sampling of sediments of both oxbow lakes was realized on 5th September 2017. Sediment cores were obtained with a "Beeker Sampler" Eijkelkamp from a boat (Figure 4). Sites evaluated as convenient for sampling are in relatively same places as sampling sites of water to chemical analysis.

The lake sediment cores were sliced into subsamples of 10 cm thickness in order to analyze each layer separately.

Figure 4: Sediment core (left) and sampling of sediment (right)

Due to relatively low background concentrations of heavy metals and As in the middle course of the Elbe River, their increased content in the sediments of researched oxbow lakes indicates anthropogenic contamination. For that reasons, the concentrations of Ag, Al, As, Cd, Cr, Cu, Fe, Hg, Ni, Pb, Zn, Ti were determined in the lake sediment profiles.

For comparability of results, it was necessary to use the same sediment grain fraction that had been used in previous research works. The use of 20μm was based on conclusions of the study by Prange et al. (1997), and other researchers (Chalupová, 2011).

Heavy metal and arsenic contents in sediment samples were obtained with the use of the aqua regia leaching method referred as "pseudo total digestion" and total digestion as well.

The difference between these two methods is that the concentrations of heavy metals and arsenic obtained by pseudo-total digestion do not include the amount of analyzed element that is contained in silicate fraction in the sediment. Therefore, the resulting metal concentration represents approximately the amount, which may be bioavailable. On the other hand, total digestion with very strong acids represents not only anthropogenic enrichment, but also total natural content of an element in the sediment.

The sediment analysis of the samples from Lake Vrť included only aqua regia leaching, in case of Lake Kozelská, both methods were applied. The concentrations of investigated elements were determined by the inductively coupled plasma optical emission spectrometry (ICP – OES). The concentration of mercury was determined using the Atomic Absorption Spectrometer AMA-254.

3 Results

3.1 Water quality

To get a broader context, the researched lakes were compared not only to each other, but also to previous studies available. As in most cases, the development of water quality parameters during the year was not evaluated, average values were used for the comparison (Table 1). Due to a different year and frequency of sampling, the comparison is only indicative.

Most of the **pH** values in Vrť and Lake Kozelská represented neutral or slightly alkaline milieu. Slight increase of pH values was measured at the end of winter and at the beginning of spring, which was driven by the increase of phytoplankton activity, when CO_2 was exhausted from water. In summer, pH in Vrť reached higher values than in Lake Kozelská, which was accompanied by significantly higher concentrations of dissolved oxygen in Vrť during these months.

In Lake Kozelská and especially in Lake Vrť, high values of **conductivity** were observed during winter, especially in January, which corresponded to higher concentrations of Ca, Cl, and N-NO3. The increase of conductivity during winter months might be caused by wash out from arable land, usage of road salts or liming of lakes (Chalupová, 2011). Higher concentrations of chlorides and phosphates could also indicate wastewater pollution (Pitter, 2015).

Concerning other oxbow lakes, Lake Kozelská showed similar values of conductivity as Lakes Obříství and Němčice (Chalupová, 2011). The highest values of conductivity measured in March corresponded to the periods of increased concentrations of inorganic nitrogen, chlorides, calcium and CODMn. Higher average values of this parameter were found in Lake Obříství also during the research carried out in 2000 and 2001 (Šnajdr. 2002).

In comparison to Vrť, Lake Kozelská showed higher concentrations of **dissolved oxygen** during summer months (Figure 5), which could be a result of dense phytoplankton population that was found in the lake. In general, lower concentrations of oxygen during warm season, which was significant especially in Lake Vrť, corresponded to higher temperatures, when the solubility of oxygen in water is lower, and to the intensification of decomposition processes when oxygen is consumed.

The decrease of oxygen concentrations could also correspond to the "clear water" period after the fall of phytoplankton, which was accompanied by high concentrations of phosphorus in water (Lellák, Kubíček, 1991).

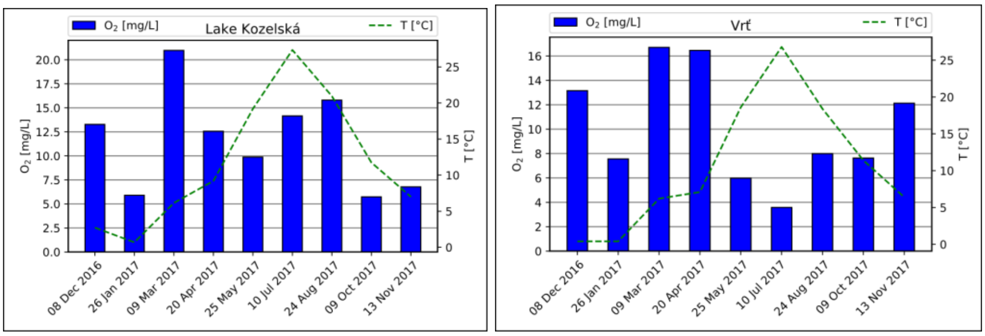

Figure 5:Concentration of O2 in Lake Kozelská (left) nad Vrť (right)

In Vrť and Lake Kozelská, **N-NO$_3$** indicating non-point sources of pollution reached the highest concentrations from all nitrogen forms especially at the end of winter and at the beginning of spring, which might be caused by wash out of fertilizers during winter precipitation and snow melting before consumption in vegetation period.

Similarly, the highest concentrations of nitrogen were determined at the end of winter and at the beginning of spring. A similar development of **N-NO$_3$** concentrations during a year as in Lake Kozelská and Vrť was also found in Němčice. The other compared oxbow lakes showed a different trend.

Concerning **N-NH$_4$**, Lake Kozelská and Vrť showed extremely high concentrations of this nitrogen form in comparison to other oxbow lakes.

In both lakes**, P-PO$_4$** (Figure 6) was depleted due to large productivity of phytoplankton in March, April and August. The highest concentrations of P-PO$_4$ were measured in May probably during “clear water” period after the fall of planktonic organisms (Kořínek a kol, 1987), when low concentrations of dissolved oxygen caused bottom anoxia allowing phosphorus releases from sediments e.g. after reduction of Fe in molecules of FePO$_4$. Higher water temperatures also intensify biochemical and decomposition processes, which could also cause phosphorus releases into water (Wetzel, 1983).

The increase of P-PO$_4$ concentrations was measured also in winter at the end of vegetation period. As both lakes were surrounded by agriculture areas, the enhanced values of phosphates could also be a result of fertilizers use in the vicinity of the lakes or other anthropogenic contamination.

In both lakes, the highest concentrations of **chlorides** (Figure 6) were reached in January, which could be related to salt wash out from roads during snow melting, or it could indicate fecal pollution coming probably from nearby villages or chemical industry, as chlorides are relatively conservative to biochemical processes in aquatic environment (Wetzel, 1983). The amount of chlorides decreased during spring and it started to raise again from July.

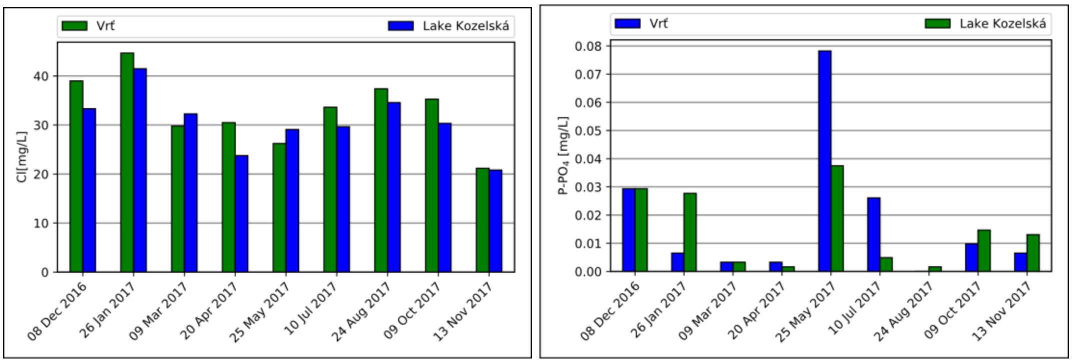

Figure 6: Concentration of Cl and P-PO$_4$ i Lake Kozelská and Vrť

Concentrations of **calcium** usually decrease due to precipitation of CaCO$_3$ during summer months as a result of intense photosynthesis of planktonic organisms causing major epilimnetic decalcification after CO_2 depletion (Wetzel, 1983). Lake Vrť showed greater changes in concentrations during the year. The maximum content of Ca was determined in Vrť in January, and in Lake Kozelská in December. During winter, the concentrations of Ca showed a positive relation with conductivity and the contents of Cl^- and $N\text{-}NO_3$ in both lakes. Higher concentrations of Ca in Lake Vrť could also be related to an anthropogenic source of pollution.

Concerning the **organic pollution** of investigated lakes, the water samples from Vrť showed higher organic load than it was determined in Lake Kozelská. In Vrť, the proportion of biodegradable substances was lower, which could be a result of hydrological communication with the Elbe River, or local sources of pollution around Lake Kozelská (fecal pollution, fertilizers).

Similar average **COD_{Mn}** values as in Vrť were determined also in Semín (Havlíková, 2011). In general, Lakes Doleháj (Chalupová, 2002), Labiště pod Opočinkem (Klouček, 2002) and Libiš (Turek, 2004) were characterized by extremely high concentrations of COD_{Mn} and BOD_5, which could probably result from a local pollution - agricultural fields with a possible application of organic fertilizers as in the cases of Doleháj and Labiště pod Opočínkem, or anthropogenic pollution from chemical industry as in the case of Libiš that is situated nearby Spolana Neratovice chemical plant.

Table 1: Chemical and physical parameters of water in the Elbe River oxbow lakes

Parametr	Kozelská tůň 2017	Vrť 2017	Vrť 2004-07	Němčice 2004-07	Lžovice 2006-07	Poděbrady 2006-07	Václavka 2006-07
O_2	11,68	10,13	**16,60**	8,27	9,86	8,67	9,66
BSK_5	5,59	2,77	4,70	4,50	3,70	3,50	5,20
$CHSK_{Mn}$	7,27	9,36	8,20	10,11	5,61	5,40	6,69
$N\text{-}NO_3$	2,27	2,24	2,58	2,10	2,10	2,60	0,10
$N\text{-}NH_4$	**0,36**	**0,45**	0,15	0,18	0,08	0,09	0,05
$P\text{-}PO_4$	0,015	0,018	0,021	**0,540**	0,080	0,040	0,040
vodivost	49,68	52,76	45,00	81,30	46,30	46,50	53,80

Parametr	Obříství 2006-07	Semín 2004-07	Votoka 2004-07				Doleháj 2003	Labiště p.O. 2002	Libiš 2007
O_2	11,46	2,30	12,00	11,47	5,48	7,30			
BSK_5	6,30	5,80	5,20	**9,23**	**17,73**	5,80			
$CHSK_{Mn}$	7,98	9,30	8,30	**25,57**	**20,12**	**18,10**			
$N\text{-}NO_3$	**3,10**	0,50	2,67	2,60	0,87	1,50			
$N\text{-}NH_4$	0,11	0,08	0,07	1,20	0,59	0,40			
$P\text{-}PO_4$	0,070	0,003	0,004	0,020	**0,410**	0,110			
vodivost	**69,40**	44,80	**78,10**	49,50	39,50	**129,00**			

3.2 Statistical evaluation of water quality

Obtained data about water quality of investigated oxbow lakes were analyzed with the Principal component analysis (PCA) using Python 3.6., package sklearn. In the case of Lake Kozelská, mean of each parameter from both. Sampling sites was used for analysis in order to evaluate more representative values. Day and month of sampling with initial letter of analyzed lake were used as categorial variable (Herben, Münzbergová, 2003)

At first, values of water quality parameters were standardized due to different units. Resulting ordination diagram (Figure 7) shows the similarity or difference of each measurement in multidimensional space (Chalupová, 2011).

The first axis, which describes the most significant gradient of measured parameters at the dates, explained 35,9 % of variability. The second axis explained 19 % of variability.

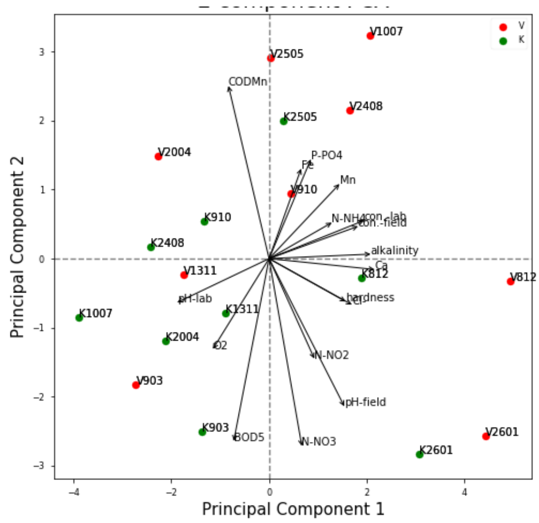

Figure 7: PCA analysis - correlation of chemical parameters

As the length of the vector representing COD_{Mn} in Figure 7 shows, this parameter occurred in the highest relative concentrations. On the contrary, the amount of N-NH_4 was represented by the lowest relative values. The angle between the vectors represents correlation rate among parameters. Fe with P-PO_4, N-NO_2 with pH, water hardness with chlorides, and N-NH_4 with conductivity were most positively correlated parameters. Scores in the graph represent location and date of the sampling. Green scores symbolize Lake Kozelská and red points represent Vrť. Numbers show date of a measurement in a format of day and month (K2004 means sampling in Lake Kozelská on 20^{th} April).

Sample scores located near the center of graph are represented by approximately mean values of measured parameters, on the other hand, scores away from the center show extreme values of certain parameters. This distribution was observed mostly in the case of Lake Vrť. As the proximity of the sample scores corresponds to similar values of the measured parameters, it can be stated that the major difference among samples was found in July, on the other hand, quite similar water quality was found in both lakes e.g. in November, January, March and May.

3.3 Analysis of zooplankton

The number of zooplankton species determined in the samples taken in the investigated lakes was lower compared to the results of other studies, as the sampling was carried out in pelagic zone, which due to its lover diversity, and usually also availability of nutrients, does not provide habitat to so many species (Ošmera, 1973). The samples collected from the pelagic zone could also be underestimated due to sampling during the day when certain species could hide in the littoral (Hrbáček, 2000a).

Lake Kozelská was represented mostly by *Arthropoda*, which were the most numerous phylum in August and in October as well (Figure 8). Regarding species distribution in Lake Kozelská, *Polyartha vulgaris*, *Bosmina longirostris* and subphylum *Copepoda* occurred the most. *Daphnia s.p.* was also found in Lake Kozelská (Figure 9). Due to the zooplankton composition, planktivorous fish were probably less represented, however, zooplankton composition could also depend on the age of fish (Hrbáček, 2000a).

In Vrť, phylum *Rotifera* showed the highest relative abundance in August, while *Arthropoda* dominated in October. Species as *Coleps hirtus*, *Polyartha vulgaris* and subphylum *Copepoda* were determined the most.

In general, all compared lakes represented mostly eutrophic aquatic ecosystems with zooplankton structure depended on the availability of nutrients (phytoplankton biomass), the character of the water body (shading), as well as the predation pressure of the fish.

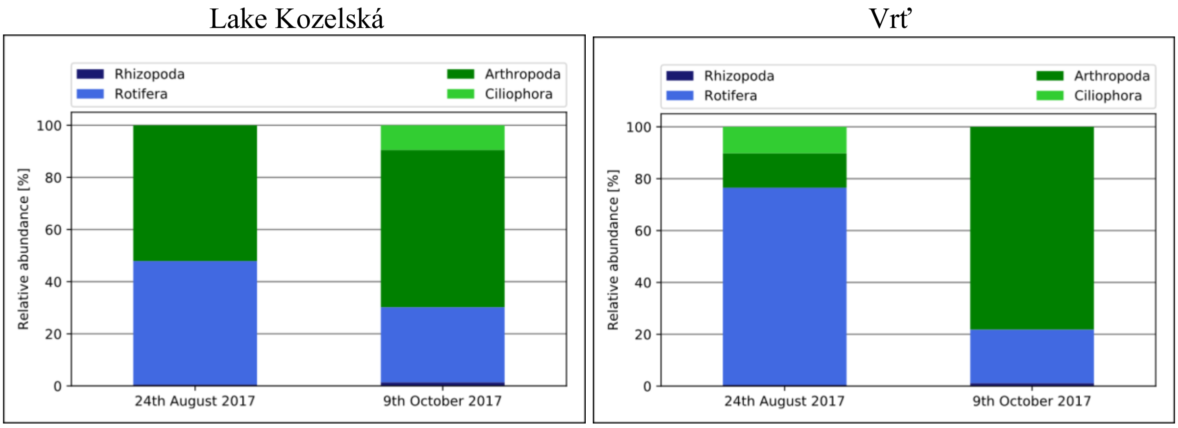

Figure 8: Relative abundance of zooplankton in Lake Kozelská (left) and Vrť (right)

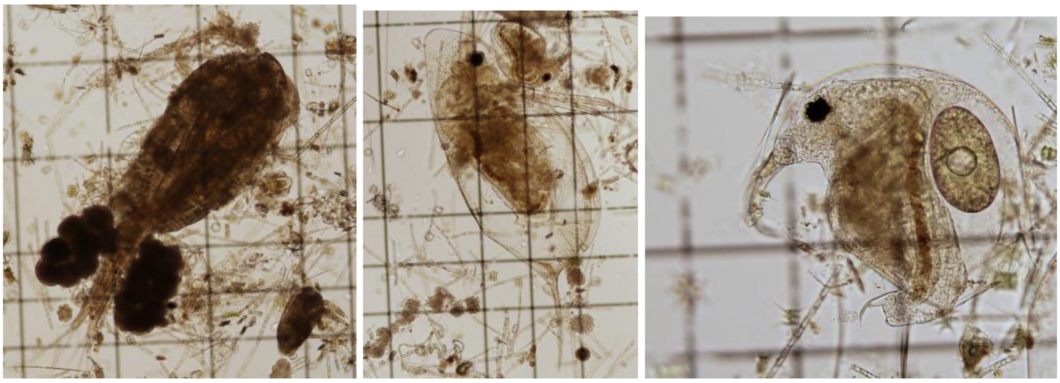

Figure 9: Acanthocyclops vernalis (left), Daphnia longispina (middle), Bosmina longirostris (right)

3.4 Sediments quality

Sediment cores from both lakes showed a different distribution of heavy metals and As in sediment layers (Figure 10). In Vrť, the concentrations of almost all investigated elements were lower and showed only small differences of their content with the depth of the sediment core.

In Lake Kozelská, the opposite situation was found. Concentrations of determined elements reached mostly higher values and their content changed a lot with the depth of the sediment core.

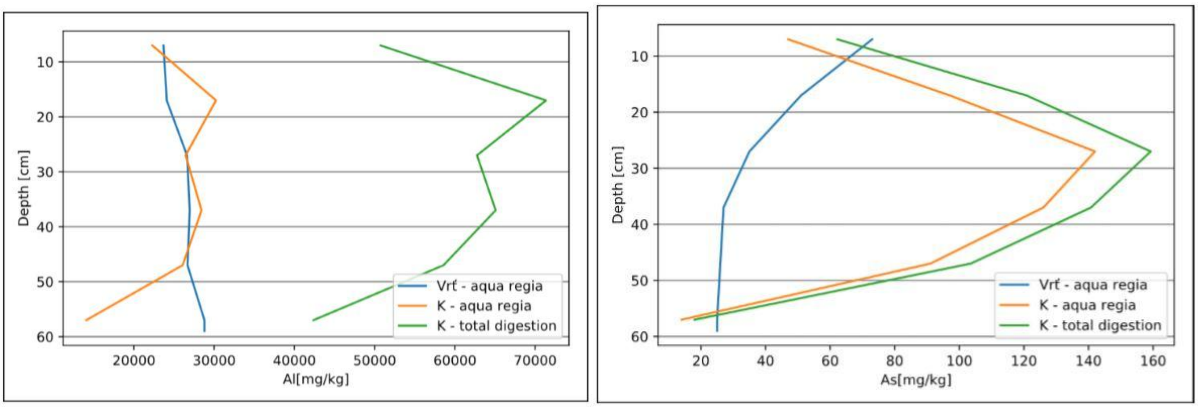

Figure 10: Concentration of Al and As in sediments

Although these changes could be influenced by dredging of sediments during communist regime or extreme flood in the locality, the high concentrations resulted probably from the situation of the lake about 2 km upstream from Spolana Neratovice, the chemical plant, which represented one of the biggest sources of pollution of the Elbe River in the past. During extreme flooding, suspended matter with adsorbed pollution could be transported even upstream, and then settled in Lake Kozelská, which could probably happen during the flood in 2002.

Regarding different digestion methods, higher concentrations were found after total digestion than after aqua regia leaching, because even very durable forms (silicates) are decomposed with this method including natural background. Concerning contamination assessment, Indices of Geoaccumulation counted with the use of background values determined by Turekian and Wedepohl (1961) shower higher class of sediment pollution than after using the background values determined in the Elbe riverbasin by Prange (1997), which took into account the specifics of the natural background of the region (Table 2 and 3).

Table 2: Classification of sediments according to Igeo

Element	I_{geo}					
	GHW - **Kozelská** total *digestion*	GHW - **Kozelská** *aqua regia*	GHW - **Vrť** *aquq regia*	T & W - **Kozelská** *total digestion*	T & W- **Kozelská** *aqua regia*	T & W- **Vrť** *aqua regia*
Ag	4,01	4,76	4,15	6,11	6,84	6,25
Al	-1,18	-2,43	-2,33	-1,04	-2,29	-2,18
As	1,48	1,26	0,06	2,37	2,14	0,94
Cd	3,60	3,36	1,97	4,02	3,78	2,39
Cu	1,33	1,38	-0,04	0,84	0,89	-0,53
Fe	-0,52	-0,58	-1,12	-0,50	-0,57	-1,11
Ni	-0,87	-0,93	-1,17	-1,23	-1,29	-1,53
Pb	1,95	1,93	-5,51	2,48	2,47	1,15
Ti	-1,62	-4,02	-4,29	-1,26	-3,66	-3,93
Zn	1,81	1,85	-0,03	2,47	2,50	0,63

Table 3: Igeo classification of sediment pollution

I_{geo} value	I_{geo} class	Sediment pollution
≤ 0	0	unpolluted
≤ 1	1	unpolluted to moderately polluted
≤ 2	2	moderately polluted
≤ 3	3	moderately to strongly polluted
≤ 4	4	strongly polluted
≤ 5	5	strongly to extremely polluted
≥ 5	6	extremely polluted

3.4.1 Sediment pollution in the Elbe River floodplain

To get a wider context of the Elbe River sediment oxbow lake pollution, a comparison with previous studies was done. Mean concentrations of investigated elements in different oxbow lakes are shown in Table 3. Different color represents the class of Igeo in each sediment core using the background values determined by Prange et al. (1997).

The contents of determined elements in sediment of the investigated lakes were compared to the results from sediment research that was carried out in Lakes Němčice, Lžovice, Poděbrady, Václavka, Obříství (Chalupová, 2011), Labiště pod Opočínkem (Klouček, 2002) and Doleháj (Chalupová, 2003). Due to using aqua regia leaching, the concentrations were completely comparable.

Mean concentrations of metals depended on the length of sediment core. For this reason, exact lengths of collected cores from every lake are shown in Table 4.

Generally, the sediments of most of the selected oxbow lakes of the Elbe River showed high contamination load with silver and cadmium. In some lakes, higher pollution was also determined in cases of mercury and lead. The contents of nickel and iron showed the same class of contamination among all compared oxbow lakes.

The sediments from Lake Kozelská contained higher concentrations of Cd in comparison to the other lakes. Higher pollution of the sediments of the Elbe River oxbow lakes was recorded mainly near the significant industrial sources of contamination. The intensity of communication with the river also influenced the load of metals in sediment.

The concentrations of determined elements in Lake Kozelská might be a result of its location near to Spolana Neratovice chemical plant. A significant sediment load was also found in Lake Labiště pod Opočínkem, which is located a few kilometers downstream Synthesia, a. S., In Pardubice – Semtín (Klouček, 2002). Higher pollution with silver, cadmium and mercury was also recorded in the oxbow lake near Lžovice, located further downstream of Pardubice, which could be also caused by its intense hydrological connection with the Elbe River.

Higher pollution by silver, cadmium, mercury and lead was also recorded in Lake Obříství, which is located several km downstream of Spolana Neratovice (Chalupová, 2011).

The significant influence on the sediment load in the Elbe River oxbow lakes is therefore not only the distance from the source of contamination, but also the intensity of lakes' hydrological communication with the river.

Table 4: Mean concentration of elements in mg/kg and Igeo of sediments (colours) (aqua regia leaching, T&W)

		Mean concentration [mg/kg]										
Location	**Core lengh [cm]**	**Ag**	**Al**	**As**	**Cd**	**Cu**	**Fe**	**Ni**	**Pb**	**Ti**	**Zn**	**Hg**
Vrť 2017	59	8	26517	37	2	47	32816	35	67	452	221	0,39
Kozelská tůň 2017	57	12	24588	86	6	125	47805	42	166	546	808	3,58
Němčice 2007	67	2,3	-	20	0,8	61	944	31	76	-	478	0,44
Lžovice A 2007	151	11,2	-	20	4,6	209	890	38	89	-	563	3,99
Lžovice B 2007	103	8,5	-	20	2,2	97	900	33	84	-	557	2,66
Poděbrady 2007	204	2,5	-	37	1,8	85	912	34	96	-	483	1,8
Václavka 2007	67	0,4	-	20	0,2	58	912	30	50	-	310	1,17
Obříství A 2007	163	5,8	-	25	3,1	121	928	43	124	-	594	1,36
Obříství B 2007	187	1,6	-	22	1,6	79	936	29	79	-	629	3,41
Labiště 2002	50	11,4	-	-	2,93	85,8	17860	46	112	-	653	1,258
Doleháj A 2002	30	10,9	-	-	1	37,3	11523	35,8	99,6	-	206	0,405
Doleháj B 2002	15	2	-	-	0,5	35,7	20340	41,5	96,3	-	204	0,54
Doleháj C 2002	30	3,3	-	-	1,25	41,8	23060	41	108	-	239	0,155

4 Conclusion

As number of measures has been adopted and resulted in the improvement of water contamination from point sources of pollution since the 1990s, the contamination from non-point sources is still not very successfully solved. Thanks to this situation, the investigated lakes showed higher contents of N-NO_3.

Water in Lake Kozelská and Vrť contained also the highest concentrations of N-NH_4 among the compared oxbow lakes in the middle course of the Elbe River. Lake Kozelská was also characterized by the highest average oxygen concentrations measured in July, when summer phytoplankton species developed.

In Lake Vrť, higher conductivity values were determined in spring due to snow melting causing probably wash out of chlorides or other ions into the lake.

In general, water quality of the investigated lakes corresponded to the character of oxbow lakes influenced greatly by the river and human activities in the floodplain.

Concerning biota, *Arthropoda* was the most numerous phylum in Lake Kozelská. Zooplankton composition corresponded to the abundancy of planktivorous fish (Hrbáček, 2000). In Vrť, phylum *Rotifera* showed the highest relative abundance in August, while *Arthropoda* dominated in October.

Lake Vrť was also characterized by small area, which could influence zooplankton species composition too. One of the decisive factors was also the land use of nearby fields (Havlíková, 2011).

The investigated sediment samples were composed of homogeneous material without significant color changes. Their dark color indicated reduction conditions and the presence of organic matter.

In Vrť, the concentrations of almost all investigated elements were lower and showed only small differences of their content with the depth of the sediment core.

In Lake Kozelská, a different situation was found. The concentrations of determined elements reached mostly higher values, and their content changed a lot with the depth of the sediment core.

Although these changes could be influenced by dredging of sediments during communist regime or extreme floods in the locality, the high concentrations resulted probably from the situation of the lake about 2 km upstream from Spolana Neratovice, the chemical plant, which represented one of the biggest sources of pollution of the Elbe River in the past. During extreme floods, suspended matter with adsorbed pollution could be transported even upstream, and then deposit in Lake Kozelská, which probably happened during the flood in 2002.

Regarding different digestion methods, higher concentrations were found after total digestion than after aqua regia leaching. Generally, the sediments of most of the selected oxbow lakes of the Elbe River showed high contamination load with silver and cadmium. In some lakes, higher pollution was also determined in cases of mercury and lead.

The contaminated sediments of the oxbow lakes coming from the old anthropogenic contamination of the Elbe River can be remobilized during floods, for that reason, the old loads can represent a secondary source of pollution. Under certain hydrological conditions or industrial accidents, pH or redox potential can change. The stable solid forms of toxic metals can be converted to soluble forms, which can contaminate the aquatic environment. These forms are easier to consume by living organisms and thus get into the food chain. The issue of contaminated riverbed sediments should be further studied, not only with regard to metals and arsenic pollution, but also for a number of other toxic organic and inorganic substances, which may represent a significant risk to the ecosystem.

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