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Residual Metal Contamination of the Ecosystem in the Lower Course of the Jihlava River

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Abstract

In November 2001, October and November 2002, the concentrations of Hg, Cd, Pb, Cr, Cu, Zn and Ni were determined in four localities of the lower course of the Jihlava River (Czech Republic). The river water, sediments of the riverbed, zoobenthos and tissues of the fish (gill, gonad, skin, dorsal muscle) were analysed. The chub *(Leuciscus cephalus)* was used as the ichthyo-indicator. At the same time, the stability of the fish community was evaluated using electrofishing and applying basic ichthyological methods. The work links up with previous investigation of the upper course of the Jihlava River (three localities) carried out by the authors in the same way in 1999. The aim of present study was the completion of previous investigation in the whole longitudinal river profile by monitoring selected heavy metals. The highest Cr (14.290 – 77.070 mg/kg), Zn (13.600 – 92.930 mg/kg) and Ni concentrations (12.290 – 36.680 mg/kg) were found in sediments and their highest loading by all of the monitored metals (without Ni) was detected in the last downstream locality (Pohořelice). Zoobenthos was most contaminated by Zn and Cu (7.480 – 62.690 and 8.050 – 21.810 mg/kg). In the body tissues of the chubs, the highest concentrations of Cd, Hg, Cu, Zn and Ni were determined in the gills, while Pb was also high in gills but also in gonads, the skin and in the muscle tissue. Concentrations of the analysed metals in the chub muscle were (in mg/kg): Hg 0.040 ± 0.014 – 0.133 ± 0.063, Cd 0.003 ± 0.002 – 0.010 ± 0.004, Pb 0.045 ± 0.038 – 0.768 ± 0.038, Cr 0.046 ± 0.023 – 0.106 ± 0.092, Cu 0.203 ± 0.123 – 0.634 ± 0.194, Zn 4.25 ± 0.84 – 6.69 ± 2.95 and Ni 0.062 ± 0.018 – 0.103 ± 0.030. Significant differences in the chub muscle were found concerning Hg, Pb, Cu ($P < 0.01$) and Cd ($P < 0.05$). Taking into consideration the actually valid FAO/WHO limits for human consumption of chub muscle from the investigated river section, only Hg (PTWI 2.3 kg in locality 7) and Pb (PTWI 2.0 kg in locality 4) could constitute some risk for human health. The index of diversity of the fish community was 0.825 – 2.110, equitability index 0.380 – 0.793, abundance 312.6 – 2,106.5 fish/ha and biomass 46.7 – 451.5 kg/ha. The water quality was characterized as betamesosaprobic (saprobity index 1.77 – 2.18). The results of the study reveal detailed ecological data concerning heavy metals contamination of the whole Jihlava River ecosystem (water, sediment, zoobenthos, fish). The outcome of this study extends our knowledge about metals accumulation in different fish tissues (gill, gonad, skin and muscle).

Stream environment, residual metal pollution, zoobenthos, fish tissues, chub (Leuciscus cephalus)

In the Czech Republic, the former anthropogenic pollution still severely impairs the environment of the fish and, along with the disastrous mortality rate, causes chronic environmental stress with grave consequences for the physiological functions of the fish organism (Hamilton and Mehrle 1986; Hinton and Laurén 1990). Contributing to this phenomena, the occurrence of heavy metals, along with strong eutrophication, constitutes a serious problem (Hughes 1981; Smart 1981). Heavy metals are subjected to cause bioaccumulation in the food chain (Keck 1980). At the top of the food chain are fish, particularly predatory fish and long-living benthophagous species. In ecological terms, fish are irreplaceable bio-indicators of the degree of damage of the water environment (Adams 1990; Thomas 1990). Elevated levels of heavy metals in aquatic organisms, especially

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fish, represent both an ecological and human health concern. Thus the comsumption of contaminated fish is the primary route of these metals to humans and piscivorous wildlife. At the present time about 350,000 anglers are registered in the Czech Republic (3 % of Czech population) who catch between 4,000 and 5,000 tons of fish every year in surface streams and consume these fish at home.

In the Czech Republic, heavy metal distribution in aquatic ecosystems is systematically monitored only during the past 15 years. Svobodová et al. (1993) monitored foreign substances in fish of the Labe (Elbe) River. Žlábek et al. (2005) studied mercury content of fish from Elbe River and its tributaries. Svobodová et al. (1999) published data on the bioaccumulation of mercury in various fish species from the Orlík and Kamýk reservoirs on the Vltava River and data of metal contamination of brown trout in Tichá Orlice River (Svobodová et al. 2004). Heavy metal contamination of the Loučka River ecosystem was assessed by Vítek et al. (2007). The content of mercury in the basic components of the ecosystem and in the fish muscles of the Jihlava River (near Hrubšice and Mohelno) was firstly studied by Peňáz et al. (1979, 1980). Spurný and Mareš (1991) monitored the concentration of Zn, Cr, Pb, Cd and Hg in seven fish species of the Jihlava River (Dalešice and Mohelno reservoirs). Peňáz et al. (2002) determined heavy metal concentration (As, Cd, Hg, Pb, Cr, Ni, Cu, Zn) in muscles of barbel *(Barbus barbus)* from three sites of the Jihlava River (Hrubšice, upstream and downstream the effluents from the sewage plant of the Třebíč city). Spurný et al. (2002) studied the concentrations of Hg, Cd, Pb, Cr, Cu, Zn and Ni in three sampling sites of the upper course of the Jihlava River (between river kilometers 156.7 and 92.1). The river water, sediments of the riverbed, zoobenthos samples and fish body tissues of chub (gill, gonad, skin, dorsal muscle) were analysed. Contents of total mercury and mercury species (methylmercury – MeHg, inorganic mercury – Hg^{2+}) were determined by Houserová et al. (2006) in Moravian rivers Jihlava, Bečva, Loučka and Dyje. Five fish tissues (muscle, gill, liver, kidney and skin) of chub, zoobenthos, sediments and water samples were analysed.

The aim of this study was to complete the evaluation of the distribution of heavy metals in the ecosystem in the lower course of the Jihlava River, started in 1999 in three localities of the upper section of the river (Spurný et al. 2002). Four sampling sites were selected of the lower course of the river (between river kilometers 47.3 and 13.1, transition between barbel and bream zone) which flows through important town and industrial agglomerations and intensive agriculture. The concentrations of Hg, Cd, Pb, Cr, Cu, Zn and Ni were monitored in samples of the water, sediments of the river bottom, composite samples of the zoobenthos and in selected body tissues of the chub (*Leuciscus cephalus*). At the same time we studied the species diversity and ecological stability of the entire fish community in the river section.

Materials and Methods

Throughout November 2001, October and November 2002, we conducted systematic ichthyological research by means of electrofishing in four localities of the lower course of the Jihlava River to determine the abundance, biomass and species diversity [diversity index according to Shannon and Weaver (1963) and equitability index according to Sheldon (1969)] of the fish community. From each locality, 7 individual samples of the chub were taken for laboratory analyses of heavy metals. At the same time we used portable equipment to measure water temperature, pH value, conductivity and concentration of dissolved oxygen. For follow-up laboratory analyses of heavy metal concentrations we took samples of the water, sediments of the river bottom and composite samples of the zoobenthos. Zoobenthos was furthermore sampled to assess the degree of the saprobity based on saprobity indexes of the found species.

The monitored river section is characterized to be a barbel zone in transition to bream zone, for the most part with fast flowing water, stony to gravel bottom, in places with sandbanks and silts in the river bottom. The width of the riverbed ranges between 16.7 and 19.4 m. Locality No. 4 (river kilometre 47.3) is located in the highest altitude near Hrubšice village downstream the Dalešice and Mohelno reservoirs and the quality of the water is relatively high. Locality No. 5 (river kilometre 36.0) is situated downstream below the industrial town Ivančice (9,400 population; engineering and textile industries). Locality No. 6 (river kilometre 31.0) is located

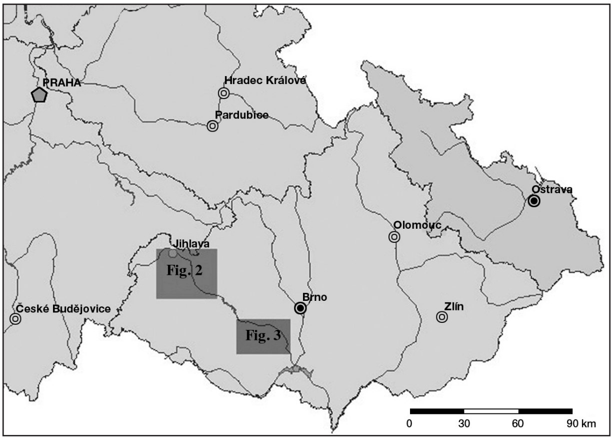

Fig. 1. Location of the Jihlava river sampling area

near Nové Bránice village in intensive agricultural region. Locality No. 7 (river kilometre 13.1) was chosen at the downstream end of the small town Pohořelice (4,500 population, engineering and food industries). A one-day excursion was devoted to reach each of these 4 localities.

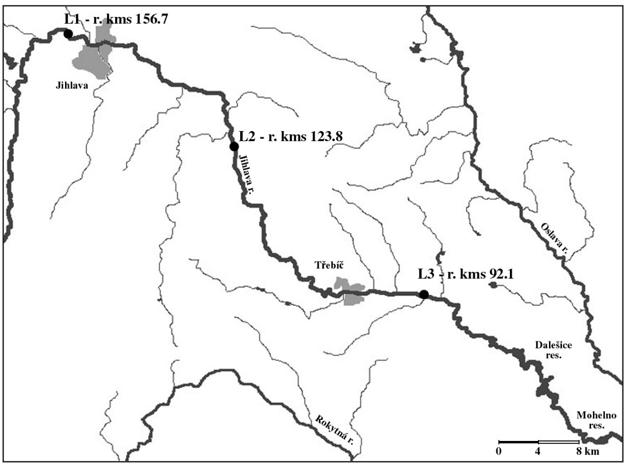

Fig. 2. Sampling sites upstream of Dalešice and Mohelno reservoirs (Spurný et al. 2002)

Samples of the fish tissues for heavy metal analyses were taken into the laboratory immediately after returning from the field excursions. For the individual assessment of heavy metals, samples of the dorsal muscle without skin, gill tissue (cut off from the gill arch), gonads and skin without scales were taken from 7 chubs from each locality. These tissue samples were immediately frozen and kept at a temperature of –18 °C together with the water, sediment and zoobenthos samples until analysis. To determine the age of the chubs, 5-8 scales were taken from each fish.

The concentration of heavy metals was analysed after dry mineralising of the fish tissues and sediments using the Czech mineralising equipment APION (producer Tessek Prague). Dry mineralising consists in drying the sample in special bowls at 105 °C for 2 hours. After cooling the bowls were transferred to the mineralising oven where the samples were incinerated in a mixture of oxidation gases (NO_x, O_3, O_2) for 12 hours under program-controlled temperatures increasing from 20 to 400 °C. The mineralised samples were then placed into a solution of 2.00 mol/l p.a. HNO_3, filtrated and the solution adjusted to 25 ml.

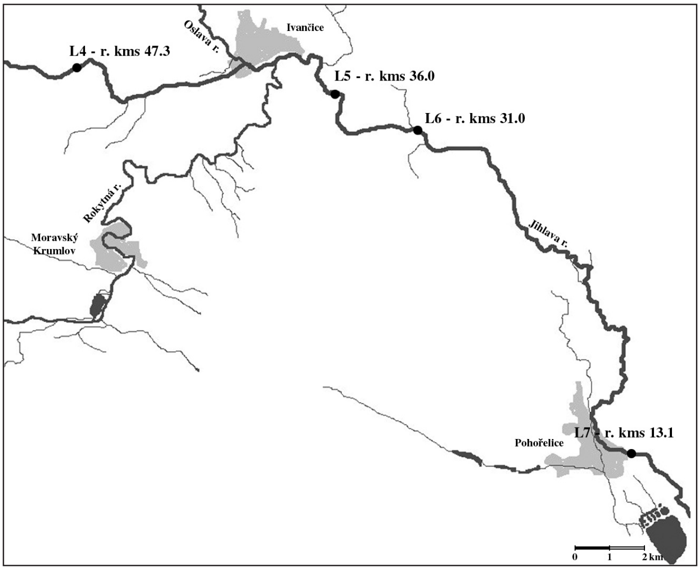

Fig. 3. Sampling sites downstream of Dalešice and Mohelno reservoirs

Mercury was analysed directly in the samples of water, sediments, zoobenthos and fish tissues on a TMA 254 apparatus (Trace Mercury Analyzer, producer VŠCHT Prague, with a detection limit of Hg 0.001 µg/kg) where sample mineralising is part of the analytical process.

Concentrations of Cd, Pb, Cr, Cu, Ni and Zn in the samples were analysed by the AAS method with electro-thermal atomisation on the SPECTR AA-30 apparatus (producer Varian Australia, with detection limits of: Cd 0.005 µg/l, Pb 0.100 µg/l, Cr 0.020 µg/l, Ni 0.080 µg/l) with electro-thermal atomiser GTA-96. The same method was used to determine the elements in the mineralised sediments, zoobenthos and fish tissues, with the exception of Cu and Zn, which were determined using the method of flame AAS on the AA 3000 apparatus (producer Perkin Elmer USA, with detection limits of: Cu 2.0 µg/l, Zn 10.0µg/l). A deuterium lamp (on the grounds of interferences caused by the matrix) was used in both apparatuses and for elements determined by the AAS method to correct the background. Standards KS 1014 (the mixture of wheat and soya meal) and KS 1015 (fish meal) from ÚKZÚZ Brno were used to verify the analytical methods of heavy metals.

The resulting concentrations of heavy metals in the body tissues of the chub were statistically processed (the same type of tissues among all of localities) using analysis of variance (ANOVA) followed by the method of Scheffe. The results are presented as mean values and standard deviation (mean values ± SD).

Results

Table 1 gives the basic characteristics of the water environment of the studied localities of the Jihlava River. In all the localities the concentrations of dissolved oxygen and pH value of the water ranged within physiological values normal for fish species of the barbel zone. The water conductivity, characterising the content of dissolved substances, increased from downstream river with 50.4 mS/m in locality 4 to 56.5 mS/m in locality 5 (downstream the town Ivančice), then moderately decreased to 53.0 mS/m in locality 6 and 54.5 mS/m in locality 7, respectively. The saprobic index, characterising the trends of organic contamination ranged in investigated river section from 1.77 in locality 5 to 2.18 in locality 7. The water quality of all the localities was classified to be betamesosaprobic. In this river section the fish community was relatively stable, with the occurrence of 12 fish species from 5 families (Salmonidae, Thymallidae, Esocidae, Cyprinidae, Lotidae). The diversity index ranged from 0.825 to 2.110, equitability index from 0.380 to 0.793, abundance from 312.6 to 2,106.5 fish/ha and biomass from 46.7 to 451.5 kg/ha, with the best ichthyological indicators in the locality 4 near Hrubšice village (Table 2).

Table 1. Environmental characteristics of the investigated course of the Jihlava River

Section (r.kms)	Sampling date	Temperature (°C) air	Temperature (°C) water	pH	Oxygen (mg/l)	Conductivity (mS/m)	Saprobity
4 (47.3)	7. 11. 2001	11.0	11.6	8.7	11.13	50.4	1.97 betameso
5 (36.0)	6. 11. 2001	13.0	9.5	8.2	11.74	56.5	1.77 betameso
6 (31.0)	31. 10. 2002	9.0	8.0	6.3	11.81	53.0	2.10 betameso
7 (13.1)	30. 9. 2002	11.0	9.6	7.2	10.58	54.5	2.18 betameso

Table 2. Characterization of fish communities in 4 sections of the Jihlava River

Section (river kilometres)	4 (47.3)	5 (36.0)	6 (31.0)	7 (13.1)
number of fish	178	70	23	29
number of species	9	5	5	6
H´	2.110	0.825	1.841	1.805
E	0.666	0.380	0.793	0.530
abundance (fish/ha)	2 106.5	618.3	474.1	312.6
biomass (kg/ha)	451.5	175.2	94.4	46.7

H´= the diversity index (Shannon and Weaver 1963)
E = the equitablity index (Sheldon1969)

Table 3 shows the analyses of heavy metals in the aquatic environment of the studied river section (water, riverbed sediments, composite samples of the zoobenthos). The concentrations of Hg, Cd, Pb, Cr, Zn, and Ni were found to be somewhat higher in the locality 4 (downstream the Dalešice and Mohelno reservoirs). The content of Hg both in the water and sediments gradually decreased downstream up to locality 7. However, we detected considerable increases of the concentrations of Cd, Pb, Cr and Cu in the water of locality 6 (near Nové Bránice village) and of Cd, Pb, Cr, Cu, Zn and Ni in the sediments of the locality 7 (Pb 10.500 mg/kg, Cr 77.070 mg/kg). However, this trend was not found in zoobenthos samples because the highest concentrations of analysed metals were detected in locality 4 and decreased considerably downstream.

Table 4 shows the average concentrations of heavy metals in gill, gonad, skin and muscle tissue of the chub. The statutory limit for Hg valid at the time of sampling

Table 3. Heavy metal concentrations, analysed in the river environment in 4 sections of the Jihlava River

Section	Specimen	Hg	Cd	Pb	Cr	Cu	Zn	Ni
4	water	1.900	0.920	4.400	1.500	4.800	13.000	2.200
	sediments	0.055	0.063	3.477	18.990	8.776	13.600	36.680
	zoobenthos	0.015	0.567	1.126	2.792	21.810	62.690	10.130
5	water	1.100	1.150	4.000	1.600	3.200	3.000	1.100
	sediments	0.008	0.045	4.843	14.290	4.079	16.370	12.290
	zoobenthos	0.019	0.069	1.423	1.280	8.050	22.070	3.190
6	water	0.110	2.000	5.000	2.600	15.000	8.000	2.700
	sediments	0.013	0.121	4.656	22.060	10.310	30.880	14.460
	zoobenthos	0.068	0.040	0.516	1.070	9.520	7.480	0.763
7	water	0.500	1.700	4.100	1.500	20.000	8.000	2.900
	sediments	0.056	0.245	10.500	77.070	24.010	92.930	29.480
	zoobenthos	0.024	0.218	0.620	0.292	10.950	19.730	1.368

Heavy metal concentration in water is presented in µg/l, in sediments and zoobenthos in mg/kg of the wet matter.

Table 4. Concentrations of analysed heavy metals (in mg/kg of wet matter) in the body tissues of the chub (*Leuciscus cephalus*) in 4 sections of the Jihlava River

Section	Tissue	Hg	Cd	Pb	Cr	Cu	Zn	Ni
4	gills	0.017 ± 0.006^{B}	0.023 ± 0.009^{B}	0.730 ± 0.087^{B}	0.064 ± 0.039	1.063 ± 0.135^{B}	65.48 ± 32.91	0.282 ± 0.064
age	gonads	0.025 ± 0.025^{b}	0.009 ± 0.004	0.380 ± 0.113^{B}	0.031 ± 0.030^{AB}	1.912 ± 0.415^{B}	46.16 ± 5.76^{b}	0.094 ± 0.041
6+ - 8+	skin	0.016 ± 0.010^{AB}	0.015 ± 0.003^{ab}	0.477 ± 0.209^{B}	0.121 ± 0.038^{B}	0.957 ± 0.218	54.21 ± 24.75	0.183 ± 0.083
average 7+	**muscle**	**0.082 ± 0.034^{AB}**	**0.010 ± 0.004^{b}**	**0.768 ± 0.038^{C}**	**0.046 ± 0.023**	**0.634 ± 0.194^{B}**	**5.31 ± 0.99**	**0.062 ± 0.018**
5	gills	0.004 ± 0.001^{A}	0.005 ± 0.002^{A}	0.880 ± 0.187^{B}	0.040 ± 0.021	0.990 ± 0.149^{B}	87.31 ± 30.87	0.198 ± 0.050
age	gonads	0.004 ± 0.001^{a}	0.004 ± 0.002	0.703 ± 0.165^{C}	0.016 ± 0.008^{A}	0.912 ± 0.539^{AB}	31.21 ± 12.73^{ab}	0.034 ± 0.013
5+ - 7+	skin	0.006 ± 0.004^{A}	0.036 ± 0.026^{b}	0.434 ± 0.106^{B}	0.051 ± 0.025^{A}	0.869 ± 0.124	63.94 ± 21.82	0.093 ± 0.008
average 6+	**muscle**	**0.040 ± 0.014^{A}**	**0.003 ± 0.002^{a}**	**0.604 ± 0.065^{B}**	**0.060 ± 0.036**	**0.393 ± 0.076^{AB}**	**4.25 ± 0.84**	**0.072 ± 0.049**
6	gills	0.011 ± 0.005^{AB}	0.019 ± 0.007^{AB}	0.090 ± 0.068^{A}	0.074 ± 0.037	0.757 ± 0.166^{AB}	64.66 ± 17.33	0.267 ± 0.093
age	gonads	0.010 ± 0.004^{ab}	0.011 ± 0.007	0.032 ± 0.027^{A}	0.050 ± 0.014^{AB}	1.309 ± 0.661^{AB}	45.48 ± 19.07^{ab}	0.080 ± 0.039
4+ - 7+	skin	0.021 ± 0.008^{AB}	0.012 ± 0.006^{a}	0.056 ± 0.023^{A}	0.092 ± 0.016^{AB}	0.829 ± 0.281	56.36 ± 9.43	0.178 ± 0.088
average 5+	**muscle**	**0.080 ± 0.014^{AB}**	**0.006 ± 0.004^{ab}**	**0.045 ± 0.038^{A}**	**0.075 ± 0.048**	**0.424 ± 0.143^{AB}**	**6.69 ± 2.95**	**0.086 ± 0.056**
7	gills	0.022 ± 0.007^{B}	0.010 ± 0.004^{A}	0.106 ± 0.047^{A}	0.054 ± 0.026	0.608 ± 0.203^{A}	71.60 ± 17.98	0.219 ± 0.091
age	gonads	0.014 ± 0.004^{ab}	0.008 ± 0.004	0.151 ± 0.036^{A}	0.117 ± 0.082^{B}	0.530 ± 0.430^{A}	24.15 ± 9.64^{a}	0.084 ± 0.030
5+ - 8+	skin	0.051 ± 0.039^{B}	0.015 ± 0.006^{ab}	0.116 ± 0.044^{A}	0.084 ± 0.045^{AB}	0.706 ± 0.232	45.51 ± 17.74	0.157 ± 0.094
average 6+	**muscle**	**0.133 ± 0.063^{B}**	**0.005 ± 0.002^{ab}**	**0.134 ± 0.105^{A}**	**0.106 ± 0.092**	**0.203 ± 0.123^{A}**	**5.40 ± 1.45**	**0.103 ± 0.030**
Czech hygienic limit+		**0.1**	**0.05**	**0.2**	**4.0**	**10.0**	**80.0**	**0.5**

$^{+}$Decreed by the Czech Ministry of Health (Law Gazette No. 53/2002) valid in the time of sampling

No significant differences were found between the values indicated by the same letters. In case of their total absence in any of the examined parameters, the values are not indicated. Small letters are used for indicating the statistical significance of differences at the level of $P < 0.05$ and capital lettres for $P < 0.01$, respectively

(0.1 mg/kg for non-predatory fish species) in the muscle tissues was slightly exceeded only in locality 7 (0.133 mg/kg) and this value was higher ($P < 0.01$) compared to locality 5. The limit concentration of Pb (0.2 mg/kg) in fish muscle were strongly exceeded in locality 4 (0.768 mg/kg, highly significant compared to the other localities) and in locality 5 (0.604 mg/kg). The concentrations of Cd, Cr, Cu, Zn and Ni in the muscle tissue did not exceed the statutory limits. The concentrations among the localities did not differ concerning Cr, Zn and Ni but revealed different values for Cd ($P < 0.05$) and for Cu ($P < 0.01$).

In the other fish tissues, the statutory limit of Pb was highly exceeded in locality 4 (0.730 mg/kg in gill, 0.380 mg/kg in gonad, 0.477 mg/kg in skin) and also in locality 5 (0.880 mg/kg in gill, 0.703 mg/kg in gonad, 0.434 mg/kg in skin). The concentrations of the other analysed metals in gill, gonad and skin were below admissible limits.

Considerably higher concentrations of heavy metals (with the exception of Hg) were detected in gill tissue of the analysed fish in most of the localities. These data correspond with concentrations found in the water of the localities. Generally, the heaviest contamination of body tissues of the fish with heavy metals (except for Hg and Cd) was detected in localities 4 and 5, i.e. downstream below the Dalešice and Mohelno reservoirs and the town Ivančice.

According to the actually valid FAO/WHO limits, the maximum tolerable daily or weekly human intakes of the muscle of chub from investigated river section are included in Table 5. Among the detected metals, only Hg (PTWI 2.3 kg in locality 7) and Pb (PTWI 2.0 kg in locality 4) can constitute some risk for human health.

Table 5. Maximal chub muscle intake from the lower course of the Jihlava River according to FAO/WHO limits (in kg/60 kg body mass of human consumer)

Metal	Hg	Cd	Pb	Cr	Cu	Zn	Ni
Limit (µg/kg)	5 PTWI	7 PTWI	25 PTWI	-	500 PMTDI	1000 PMTDI	-
Intake (locality)	2.3 (7)	42.0 (7)	2.0 (4)	-	47.3 (4)	9.0 (6)	- -

PTWI-provisional tolerated weekly intake, PMTDI-provisional maximum tolerable daily intake

Discussion

In comparison with the upper course of the Jihlava River (Spurný et al. 2002; Houserová et al. 2006), the concentrations of heavy metals in the aquatic environment of the lower course of the river in general gradually decreased (except for the content of Cr, Cu and Ni in riverbed sediments of locality 7). In comparison with locality 1, the accumulation of Cr increased in sediments of locality 7 nearly 10-fold (up to 77.070 mg/kg). Increased amounts of metals deposited within sediments mean as a consequence to bear an ecological risk in case of their sudden release from sediments due to hydrological changes. The highest content of analysed metals in zoobenthos samples was detected in locality 4 (downstream the Dalešice and Mohelno reservoirs) which represents the most contaminated locality of the investigated lower section of the river, following the significant pollution of locality 3 (Vladislav) situated upstream these reservoirs. In accordance with this trend, Houserová et al. (2006) found at the same locality the highest content of total Hg in the sediment (0.225 mg/kg in dry matter) and in zoobenthos (0.265 mg/kg in dry matter) from the Jihlava River suggesting an influence of Dalešice and Mohelno reservoirs on aquatic fauna. Fish fauna cannot naturally migrate due to dams, therefore fish from the more contaminated upstream area do not appear in the downstream water which is less polluted. In addition, Spurný and Mareš (1991) determined concentrations of Hg in the muscle of perch (4-5 years old) from the Dalešice reservoir ranging between 0.63 and 0.78 mg/kg and in the muscle of a 7-year-old roach 0.48 mg/kg. Vítek et al. (2007) found in sediments of the upper and middle course of the Loučka River (right-side tributary of the Svratka River) similar concentrations of Cd (0.303 mg/kg) and of Pb (12.050 mg/kg), but higher concentrations of Hg (0.208 mg/kg) and Cu (80.200 mg/kg) and lower contents of Cr (36.196 mg/kg), Zn (75.100 mg/kg) and Ni (24.980 mg/kg) compared to the investigated section of the Jihlava River. Heavy metal contamination of zoobenthos in the Loučka River (Vítek et al. 2007) is very similar (only maximum concentrations of Cr – 3.832 mg/kg and Cu – 74.300 mg/kg are higher and that of Ni – 1.505 mg/kg is lower) to the Jihlava River.

The content of Hg in muscle tissue of the chub in locality 4 (0.082 mg/kg) was dramatically lower than in locality 3 (Vladislav – 0.136 mg/kg) furthermore decreasing in locality 5 (0.040 mg/kg) and showing a strong increase up to 0.133 mg/kg in locality 7. Peňáz et al. (1979) determined the Hg content in muscle tissue of the chub near Hrubšice (our locality 4) to be within 0.14 – 0.22 mg/kg. In this locality Peňáz et al. (2002) reported that the concentration of Hg in the muscle tissue of barbel (age from 3+ to 9+ years) ranged from 0.030 to 0.113 mg/kg. Houserová et al. (2006) analysed total Hg content in chub muscle near Hrubšice and revealed a value of 0.135 mg/kg in dry matter which was 7-times lower compared to the muscle samples from Vladislav (0.962 mg/kg in dry matter). Žlábek et al. (2005) published average concentrations of Hg in chub muscle from Elbe River, Vltava River and Blanice River to be in the range of 0.141 to 1.631 mg/kg and Svobodová et al. (1993) detected 1.600 mg/kg of Hg in perch muscle from Elbe River near Čelákovice. Vítek et al. (2007) determined 0.390 mg/kg of Hg in brown trout muscle from Loučka River and Svobodová et al. (2004) detected 0.410 mg/kg of Hg in the muscle tissue of the same fish species derived from Tichá Orlice River. In comparison with the above mentioned values from other Czech rivers, the Hg contamination of chub muscle from Jihlava River seems to be much lower. Comparing the contents of Pb and Cr in chub muscle derived from locality 4 with the results of Peňáz et al. (2002) in barbel muscle, Pb contents were10-fold higher in chub (0.768 mg/kg) compared with barbel (< 0.050 – 0.066 mg/kg) and Cr had 7.5-times lower concentrations in chub (0.046 mg/kg) compared to barbel (0.083 – 0.345 mg/kg). Concerning the concentrations of the further analysed metals (Cd, Cu, Zn and Ni) only minor differences were found between chub and barbel. However, we should take into consideration that barbel represents a distinct benthophagous and very slow growing fish species and is assumed also to have a higher bioaccumulation rate for heavy metals. Vítek et al. (2007) found in brown trout muscle from Loučka River average concentrations for Pb in the range of 0.108 – 1.010 mg/kg, for Cr of 0.028 – 0.073 mg/kg, for Cu of 0.329 – 0.399 mg/kg and for Zn of 3.956 – 5.801 mg/kg. Svobodová et al. (2004) reported in the upper course of Tichá Orlice River maximum contamination of brown trout muscle by Cr of 0.081 mg/kg, by Cu of 0.343 mg/kg and by Zn of 4.53 mg/kg. In the case of Pb, Cr and Cu our results are very similar, but the maximum content of Zn in chub muscle from the Jihlava River (6.69 mg/kg) was 1.5-times higher compared to that one from the Tichá Orlice River.

Houserová et al. (2006) found the lowest concentrations of total Hg in gill and skin of all tested chubs. The Hg content in investigated tissues decreased in the following order: muscle >> kidney ≈ liver > skin ≈ gill. In our study we found this trend also in tissues of chub (muscle, gill, gonad, skin) for Hg (muscle >> gill ≈ gonads ≈ skin). In the case of Cd, Pb, Cr, Cu, Zn and Ni we found the highest contents in gill and skin of the fish derived from all localities. Higher concentrations of these metals (except for Cr) were also detected in the gills and skin of chub from the upper course of the river (Spurný et al. 2002). Therefore, analyses of these directly exposed tissues, especially of gills, have a high bio-indicative value for the quality of the aquatic environment, because the pollutants enter the tissues directly, and not via the food chain. The increased contents of Cu was also recorded in chub gonads from localities 4 (1.912 mg/kg), 5 (0.912 mg/kg) and 6 (1.309 mg/kg). The high concentrations of Pb in gonads from localities 4 (0.380 mg/kg) and 5 (0.703 mg/kg) and of Cr from locality 7 (0.117 mg/kg) might even disturb natural reproduction of fish.

The specific heavy metal pollution of the aquatic environment of the Jihlava River corresponds with their contents in monitored tissues of chub and appears to be relatively high in the upper course of the river, especially downstream to large industrial impacts by the towns Jihlava and Třebíč. The high loading of the ecosystem by heavy metal pollution persists still downstream the Dalešice and Mohelno resevoirs and decreases consecutively downstream to the lower river sections. An important ecological hazard is given by enhanced contents of heavy metals in riverbed sediments of locality 7 (Pohořelice). Generally, downstream the loading of the river by these specific pollutants decreases and corresponds with a trend of decreased organic contamination. The saprobity index gradually decreases from the 1st to the 5th locality with a moderate increase in localities 6 and 7. In the 3rd locality the alphamesosaprobity converts into betamesosaprobity and persists at this level along the lower course of the river.

The results of our study did not confirm the assumption that the Jihlava River was generally considered to be one of the most heavily polluted Czech rivers concerning Hg (Moldán et al. 1990). However, Houserová et al. (2006) found that Hg contamination of muscle samples of chub from Loučka, Dyje and Bečva Rivers were approximately two times lower compared to samples from the Jihlava River (sampling site Vladislav) where also the highest contents were found in sediment and zoobenthos samples. Moreover, our study proved some risk for human consumption of fish caught inthe lower course of the river in the case of Hg and Pb.

Zbytkové znečištění ekosystému dolního toku řeky Jihlavy těžkými kovy

V listopadu 2001, říjnu a listopadu 2002 byla zjišťována koncentrace Hg, Cd, Pb, Cr, Cu, Zn a Ni na čtyřech lokalitách dolního toku řeky Jihlavy. Analýzy byly prováděny v říční vodě, sedimentech dna, vzorcích zoobentosu a v tělních tkáních ryb (žábry, gonády, kůže, hřbetní svalovina). Jako ichtyoindikátor byl použit jelec tloušť *(Leuciscus cephalus)*. Současně byl pomocí elektrolovu a základních ichtyologických metod hodnocen stav rybího společenstva (abundance, biomasa, index diverzity, index ekvitability) a podle druhového složení společenstva zoobentosu zjišťován index saprobity. Cílem sledování bylo dokončit zmapování distribuce těchto polutantů v celém toku řeky Jihlavy, zahájené v roce 1999 autory této studie na třech lokalitách horního toku řeky. Nejvyšší koncentrace Cr (14,290 – 77,070 mg/kg), Zn (13,600 – 92,930 mg/kg) a Ni (12,290 – 36,680 mg/kg) byly zjištěny v sedimentech dna, jejichž nejvyšší zátěž všemi sledovanými kovy (s výjimkou Ni) byla detekována na nejníže po proudu ležící lokalitě (Pohořelice). Zoobentos byl nejvíce kontaminován Zn a Cu (7,480 – 62,690 a 8,050 – 21,810 mg/kg). V tělních tkáních jelce tloušťě byly nejvyšší hodnoty kadmia, olova, mědi, zinku a niklu zjištěny v žábrách, v případě olova také v gonádách, kůži a ve svalové tkáni. Koncentrace analyzovaných kovů ve svalové tkáni jelce tlouště dosahovaly následujících hodnot (v mg/kg): Hg 0,040 ± 0,014 – 0,133 ± 0,063; Cd 0,003 ± 0,002 – 0,010 ± 0,004; Pb 0,045 ± 0,038 – 0,768 ± 0,038; Cr 0,046 ± 0,023 – 0,106 ± 0,092; Cu 0,203 ± 0,123 – 0,634 ± 0,194; Zn 4,25 ± 0,84 – 6,69 ± 2,95 and Ni 0,062 ± 0,018 – 0,103 ± 0,030. Vysoce průkazné rozdíly ($P < 0,01$) v koncentraci sledovaných kovů ve svalovině jelce tlouště byly zjištěny v případě Hg, Pb a Cu, v případě Cd potom průkazné ($P < 0,05$) rozdíly. V souladu s aktuálně platnými limity FAO/WHO pro lidský konzum svaloviny jelce tlouště ze sledovaného říčního úseku pouze rtuť (PTWI 2,3 kg na lokalitě 7) a olovo (PTWI 2,0 kg na lokalitě 4) mohou představovat určité riziko pro lidské zdraví. Index diverzity rybího společenstva dosahoval rozpětí 0,825–2,110, index ekvitability 0,380–0,793, abundance 312,6–2.106,5 ks/ha a biomasa 46,7–451,5 kg/ha. Kvalita vody byla charakterizována jako betamesosaprobní (index saprobity 1,77 – 2,18).

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