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Environmental study of some metals on several aquatic macrophytes

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Aquatic macrophytes can be used in the study of quality of water ecosystems and in monitoring of metals and other pollutants. This study was focused on assessment of metals accumulation in certain aquatic macrophytes (biomonitors), in comparison with water and sediment (abiotic monitors) of the lake. Concentrations of Fe, Mn, Cu and Pb were measured in water, sediment and plant samples, namely in stems and leaves of *Bidens tripartitus* L., *Polygonum amphibium* L., *Lycopus europaeus* L. and in roots, stems and leaves of two aquatic plants, *Typha angustifolia* L. and *Typha latifolia* L. The concentrations of all investigated metals were higher in sediment than in water. The mean concentrations of metals in macrophytes were sequenced: Fe > Mn > Cu > Pb. This study exhibited different metals concentration in aquatic plants, depending on the plant organ. The highest concentrations of Fe and Pb were recorded in root of *T. latifolia* L. As means of Mn and Cu, their concentrations were higher in stems and leaves of different investigated species. The application of macrophytes can be possible in finding of solutions for problems of protection, sanation and revitalization of different aquatic ecosystems.

Key words: Aquatic macrophytes, metals (Fe, Mn, Cu and Pb), lake contamination.

INTRODUCTION

Heavy metals are important environmental pollutants and many of them are toxic even at very low concentrations. Industrial pollutants, heavy metals, in contrast with organic material cannot be degraded and therefore accumulate in water, soil, bottom sediment and living organisms. Water contamination with heavy metals is a very important problem in the contemporary world. The main processes by which heavy metals are removed from aquatic environment are physical, biological and biochemical and they take place in water, biota and suspended solids. The predominance of one of them will

depend on the composition of the system, the pH, the redox condition, and the pollutant nature (Miretzky et al., 2004). Phytoremediation is defined as the use of plants to remove pollutants from the environment and presents an effective alternative in removing heavy metals from soil, wastewater and sludge. Macrophytes are aquatic plants that grow in/or near water and can be classified as emergent, submerged or floating plants. Studies were done in investigating the capabilities of some macrophytes to remove different concentration of heavy metals (Maine et al., 2001; Maine et al., 2004; Skinner et al., 2007); in the role as biomonitors of environmental metal levels (Pajević et al., 2003, 2004; Mishra et al., 2008) and in their ability as biological filters of the aquatic environment (Uphadhay et al., 2007).

Aquatic plants are well known for accumulating and concentrating great various substances among them metals, which they take from the environment and concentrate on the trophic chains with accumulative effect, and they are consequently useful indicators of local

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Abbreviations: ECS, Enrichment coefficient for stem; ECL, enrichment coefficient for leaf; TLF, transfer factor; ECR, enrichment coefficient for roots; CF, concentration factor.



Figure 1. Location of Kragujevac city.

pollution. Some of the plant species can accumulate very high concentrations of toxic metals to levels which exceed far the soil levels (Baker and Brooks, 1989). From soil and water, all plants have the ability to accumulate heavy metals which are essential for their growth and development such as Mg, Fe, Mn, Zn, Cu, Mo and Ni. Certain plants also have the ability to accumulate heavy metals which have no known biological function. These include Cd, Cr, Pb, Co, Ag, Se and Hg (Memon et al., 2001). Metal uptake by plants depends on the bio-availability of the metal in the water phase, which in turn depends on the retention time of the metal, as well as the interaction with other elements and substances in the water (Fritioff and Greger, 2003).

Heavy metals are persistent and accumulate in water, sediment and into tissues of the living organisms, through two mechanisms, namely "bioconcentration" (uptake from the ambient environment) and "biomagnification" (uptake through the food chain) (Chaphekar, 1991). Plants have developed three basic strategies for growing on contaminated and metalliferous soils (Baker and Walker, 1990). Metal excluders are plants which effectively prevent metal from entering their aerial parts over a board range of metal concentrations in the soil. However, they can still contain large amounts of metals in their roots. Metal indicators are plants which accumulate metals in their above-ground tissues and the metal levels in the tissues of these plants generally reflect metal level in the soil. They tolerate the existing concentration level of metals by producing intracellular metal binding Compounds (chelators), or alter metal compart-mentalization pattern by storing metals in non-sensitive parts.

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Accumulators are plant species (hyperaccumulators) which can concentrate metals in their above-ground tissues to levels far exceeding those present in the soil or in the non-accumulating species growing nearby (Baker and Walker, 1990). Baker and Brooks (1989) have defined metal hyperaccumulators as plants that contain more than 0.1% of copper, cadmium, chromium, lead, nickel and cobalt, or 1% of zinc or manganese in dry matter. For cadmium and other rare metals, it is more than 0.01% by dry weight (Baker and Brooks, 1989; Baker and Walker, 1990; Salt et al., 1998). The extent of metal adsorption and its distribution in plant seems to have important consequences in the capacity and rate of metal removal, in the metal residence time and in the metal release to the environment (Ellis et al., 1994).

Aquatic plants are therefore used in water quality studies to monitor heavy metals and other pollutants of water and submerged soil. Their selective absorption of certain ions, combined with their sedentary nature makes such plants suitable as biological monitors (Sawidis et al., 1995).

The aim of study was to assess the concentration status of four metals (Fe, Mn, Cu and Pb) in selected plant parts (roots, stems and leaves) of five native aquatic macrophytes species (passive biomonitors) in comparison with sediment and water samples.

MATERIALS AND METHODS

Study area

The study areas are located near city Kragujevac in the Central part of Serbia between 44° 22' latitudes and 20° 56' longitudes (Figure 1). The study areas involved three artificial lakes near city Kragujevac.

The artificial lake Gruza was created by parting the middle flow of the river Gruza in order to supply Kragujevac and the surrounding villages with water, for the purpose of water supply industry, as protection from floods and for the retention of sediment. The Gruza lake is 10 km long and 0.3-2.8 km wide, with surface area of 934 km² (Comic and Ostojic, 2005). The artificial lake Bubanj is formed next to the asphaltenes road Kragujevac-Batocina. It was in the alluvial plain of river Lepenica, in abandoned valley where the exploitation was being carried out for the country brick factory. This lake-pond is built in the sports and recreational center, planted with fish, and it is used for sport fishing and it is a significant reservoir of biodiversity with the flora and fauna aquatic habitats (Simic et al., 1994). The lake "Memorial-park Sumarice" is located in the Memorial Park Kragujevacki October, on the outskirts of the city of Kragujevac. This accumulation was built with the intention of park irrigation, but it is not used for these purposes. It has a role in the aesthetic design of the Memorial Park, as a recreation facility for the citizens of Kragujevac, for sports and sport fishing, and for maintenance of cleanliness of the city (Pesic, 2003).

Sample collection

The field work was conducted during the summer of 2004 and 2010. Samples of water plants were taken from the sites with the greatest multitude on the lakes Gruza, Bubanj and Sumarice. Samples of surface water and sediment were collected from various areas of

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Table 1. Metal concentrations in water and sediment and ratios between the concentration in the sediment and that in the water.

Metal	water (mg l ⁻¹)	sediment (mg kg ⁻¹)	sediment/water
Fe	0.200	281.563	1407.817
Mn	-	363.687	-
Cu	0.017	20.230	1207.761
Pb	-	31.752	-
Mean	0.054	174.308	653.895
Sd	0.097	174.576	759.457

the lakes at a maximum depth of 1 m, at the same time as the plants. Soon after collection, the water samples were filtered through 0.45 µm (pore size) millipore filter and preserved in plastic bottles by addition of a few drops of nitric acid. Sediment was taken with a grab, at a depth from 0 to 10 cm, and then it was preserved in bottles, labeled carefully and brought to the laboratory for further analysis. Dominant taxa in the populations of aquatic plants were selected in order to create real representative sample. Macrophytes were collected by hand and, after careful washing with lake water to remove periphyton and sediment, were preserved in plastic bottles. Sampled plant species were: *T.angustifolia* L. (root, stem, leaf), *T.latifolia* L. (root, stem, leaf), *L.europaeus* L. (stem, leaf), *B.tripartitus* L. (stem, leaf) and *P.amphibium* L. (stem, leaf).

Determination of plant material and metals analysis

Determination of plant material was performed in the laboratory of the Institute of Biology and Ecology, Faculty of Science in Kragujevac, with the help of standard keys for determination: Javorka and Csapody (Javorka and Csapody, 1979), Flora of the Republic of Serbia (Josifovic, 1991) and Flora Europaea (Tutin et al., 2001).

Identified plant material was elutriated in distilled water and then dried at room temperature. Then it was dried in dryer (Binder/Ed15053), 24 h at a temperature 105°C and prepared for chemical analysis by standard procedures, which is used for water and water plants (according to norms APHA, 1995).

Metals that were analyzed are iron (Fe), manganese (Mn), copper (Cu) and lead (Pb). Measurement of metal concentration in plant tissues were carried out by atomic absorption spectrophotometer of company Perkin-Elmer, model 3300/96 with MHS-10 hydride system and a computer on the Agricultural Faculty in Belgrade-Zemun. Chemical analysis of water and sediment was done by standard methods, at the Institute of Public Health Division of Hygiene and Medical Ecology in Kragujevac. The metal concentrations in water and sediment were determined by atomic absorption spectrophotometer (EPSON FX-870/P710A/2JB0012273), directly from the solution. These concentrations were measured in water, sediment and plant samples, in triplet. After that their mean values were calculated. The contents of metals in water were expressed in mg l⁻¹, whereas in sediment in mg kg⁻¹ and plant materials in mg kg⁻¹ dry weight.

To quantify the comparison of the concentration of an element in an aquatic organism with the same in the water where the organism lives, it can use the ratio between the concentration of the element in the organism (related to the wet weight) and in the water. The value of this ratio is known as the concentration factor (C.F.) (De

Bortoli et al., 1968). It was calculated for all investigated plants.

Transfer factor (TLF) and Enrichment Coefficients were also calculated. Transfer factor (TLF) presents the ratio of [Concentration of element]_{leaf} / [Concentration of element]_{root}. Enrichment coefficient (EC) for elements between sediment and root and within a plant were expressed by ratios: [Concentration of element]_{root} / [Concentration of element]_{sediment} (ECR), [Concentration of element]_{stem} / [Concentration of element]_{sediment} (ECS) and [Concentration of element]_{leaf} / [Concentration of element]_{sediment} (ECL). It shows element translocation properties from sediment to roots and from roots to above ground parts of plant (Zhao et al., 2003). All results of these researches were shown by tables and figures.

RESULTS

Water and sediments

The concentrations of metals were far higher in the sediment than those calculated for the same metals in the lake water (Table 1). The concentration of Fe (0.2 mg l⁻¹) in the lake water was the highest, and in the sediment we registered the highest concentration of Mn (363.69 mg kg⁻¹). The values of the ratio between element concentrations in the sediment and those in the water were higher than 10³ for Fe and Cu. Manganese and lead were not detected in the water, due to the fact that their concentrations were lower than the detection limit of the method (detection limit for Pb in water is lower than 0.010 mg l⁻¹ and for Mn lower than 0.050 mg l⁻¹).

Macrophytes

Figure 2 shows the values of concentration of four metals (Fe, Mn, Cu and Pb) in five species of macrophytes. The mean concentration values of the metals in plants decreased according to this sequence: Fe > Mn > Cu > Pb. As for plants, their mean concentration values of investigated metals increased according to this plant sequence: *Bidens tripartitus* < *L.europaeus* < *P.amphibium* < *T.latifolia* < *T.angustifolia*. The both species of genus *Typha* had the greatest capacity for concentrating of trace elements. In fact, *T.angustifolia* showed the highest concentration of Fe and Mn, and *T.latifolia* concentrated Cu and Pb in the highest value.

The C.F. values for each species and metals are shown in the Table 2. The mean C.F. values of metals in investigated plants increased according to this plant sequence: *Bidens tripartitus* < *L.europaeus* < *P.amphibium* < *T.latifolia* < *T.angustifolia*. The mean C.F. value of Fe was higher than the mean C.F. value of Cu. Manganese and lead were not analyzed in the water, due to the fact that their concentrations were lower than the detection limit of the method, preventing the calculation of their C.F.

The mean concentration of investigated metals in roots, stems and leaves of five aquatic plants varies from

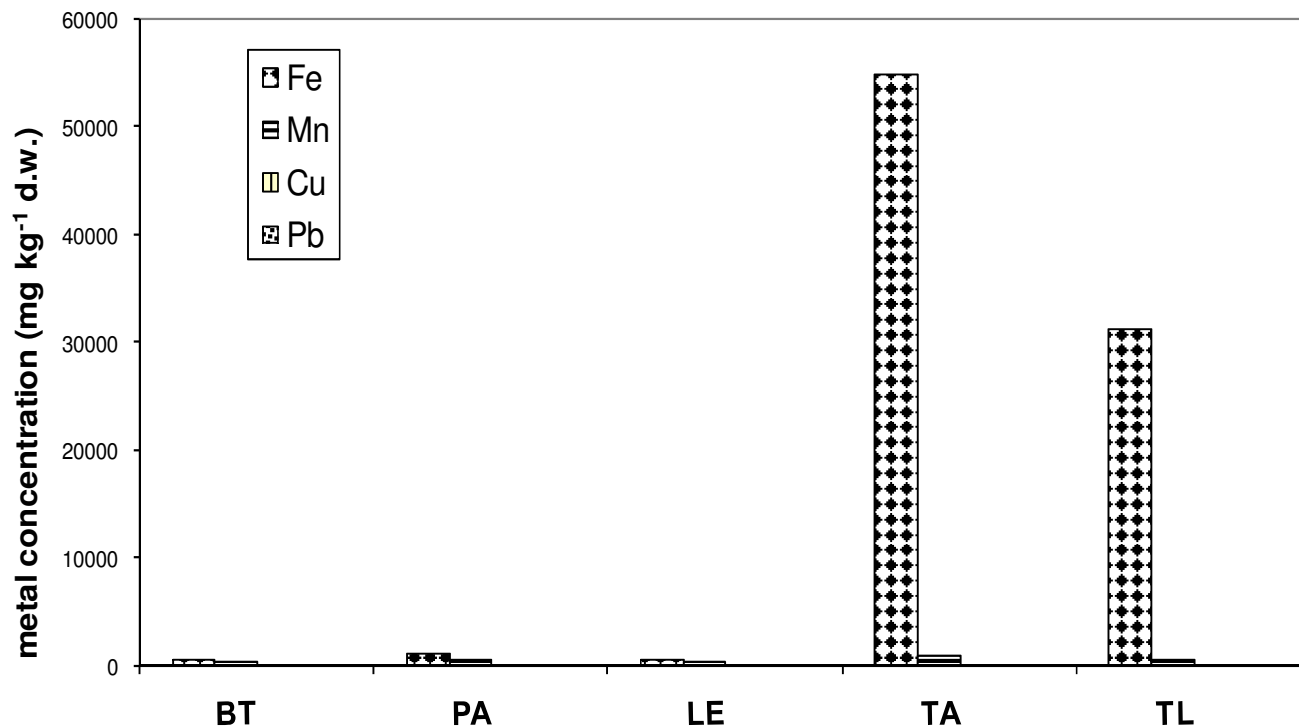


Figure 2. The mean concentration of Fe, Mn, Cu and Pb (mg kg^{-1} dry weight) in five macrophytes (BT = *Bidens tripartitus*, PA = *Polygonum amphibium*, LE = *Lycopus europaeus*, TA = *Typha angustifolia*, TL = *Typha latifolia*)

Table 2. Concentration factors (CF) calculated for the various plant species and metals.

Plant specie	Fe	Cu	Mean
<i>Bidens tripartitus</i>	2210.847	431.648	660.624
<i>Polygonum amphibium</i>	5184.685	315.881	1375.141
<i>Lycopus europaeus</i>	2901.220	508.794	852.503
<i>Typha angustifolia</i>	274294.600	442.985	68684.396
<i>Typha latifolia</i>	155863.150	585.075	39112.056
Mean	88090.900	456.876	
Sd	123258.875	99.799	

species to species (Figure 3). The results of this study indicated that both species of genus *Typha* accumulated Fe in their roots in the highest level ($92623.530 - 163451.800 \text{ mg kg}^{-1}$ dry weight). In addition, the high concentration of Fe was discovered in stem ($1428.790 \text{ mg kg}^{-1}$ dry weight) and leaves ($645.080 \text{ mg kg}^{-1}$ dry weight) of *Polygonum amphibium*. The concentration of Mn was found higher in the stem of *Bidens tripartitus* ($313.860 \text{ mg kg}^{-1}$ dry weight) and in the leaves of *T.angustifolia* ($1468.960 \text{ mg kg}^{-1}$ dry weight) and *P.amphibium* ($593.740 \text{ mg kg}^{-1}$ dry weight). The high

concentration of Cu were contented in the stem of *L.europaeus* (8.750 mg kg^{-1} dry weight) and leaves of *Bidens tripartitus* (9.080 mg kg^{-1} dry weight). The results of this study showed that Pb was the metal with the highest concentration in root ($31.230 \text{ mg kg}^{-1}$ dry weight) of *Typha latifolia*. However, the concentration of Pb was found higher in leaves (4.500 mg kg^{-1} dry weight) and stem (3.850 mg kg^{-1} dry weight) of *T.latifolia*.

Transfer factors of metals in the investigated plants are shown in Table 3. The TLFs were calculated for two species of genus *Typha* and was between 0.001024 and 1.329015. The mean values of TLFs were the highest (0.96) for Mn, and the lowest for Fe (0.0017). The transfer factor of *T.angustifolia* for Mn is 1.329.

The ECR were calculated for two species of genus *Typha* (Table 3). As for ECR, it was between 0.349 and 580.515, and it decreased according to this sequence: Fe > Mn > Pb > Cu. The enrichment coefficients calculated for selected elements in the roots of *T.angustifolia* and *T.latifolia* were higher than in the leaves and stems, except for Mn.

In our study, the mean value of ECLs was between 0.055 and 1.646 (Table 4), where the enrichment coefficients of Cu and Pb were lower than 1. On the other hand, ECL of Mn and Fe were higher than 1.0. Enrichment coefficient for the leaf higher than 1 was recorded in species *Bidens tripartitus* and *Polygonum amphibium* for Fe, and both of species of genus *Typha* and *P. amphibium* for Mn.

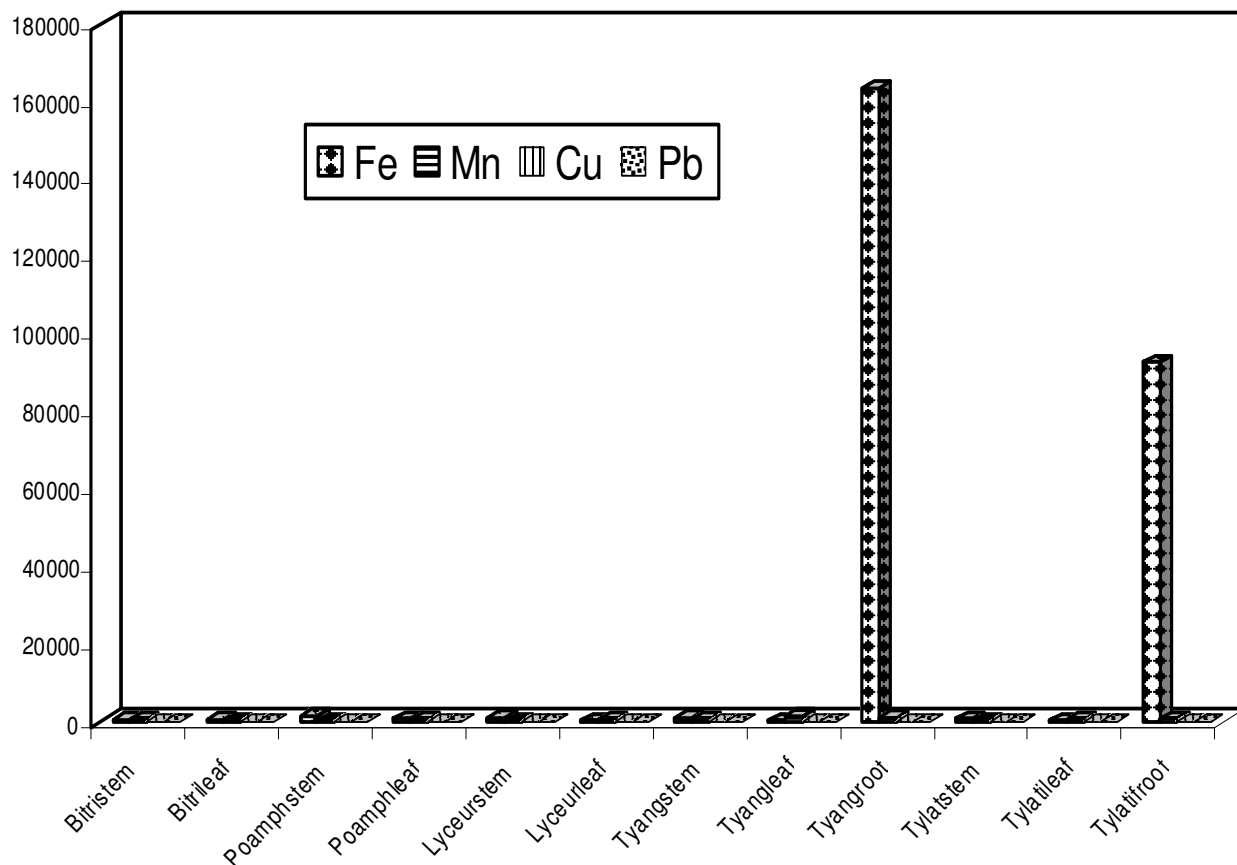


Figure 3. Concentration of Fe, Mn, Cu and Pb (mgkg⁻¹ dry weight) in leaves, stems and roots of five macrophytes (BTS = *Bidens tripartitus* - stem, BTL = *Bidens tripartitus* - leaf, PAS = *Polygonum amphibium* - stem, PAL = *Polygonum amphibium* - leaf, LES = *Lycopus europaeus* - stem, LEL = *Lycopus europaeus* - leaf, TAS = *Typha angustifolia* - stem, TAL = *Typha angustifolia* - leaf, TAR = *Typha angustifolia* - root, TLS = *Typha latifolia* - stem, TLL = *Typha latifolia* - leaf, TLR = *Typha latifolia* - root)

Table 3. Enrichment coefficient for roots (ECR) and transfer factor (TLF) for two macrophytes.

Macrophyte	Fe		Mn		Cu		Pb	
	ECR	TLF	ECR	TLF	ECR	TLF	ECR	TLF
<i>Typha angustifolia</i>	580.515	0.001	3.039	1.329	0.400	0.665	0.350	0.259
<i>Typha latifolia</i>	328.961	0.002	1.815	0.591	0.759	0.546	0.983	0.144
Mean	454.738	0.002	2.427	0.960	0.580	0.605	0.667	0.202

ECR, Enrichment coefficient for root = root/sediment; TLF, transfer factor= leaf/root.

The mean value of ECS was between 0.028 and 3.066 (Table 4). Enrichment coefficient for Fe in the stems of all researched plants was higher than 1.

In this study, overall review of transport mechanism and accumulation pattern revealed different order for each metal. In case of Fe, it was: Root system > Stem system > Leaf system > Sediment and for Mn: Root system > Leaf system > Sediment > Stem system. As for Cu and Pb, the transport mechanism and accumulation pattern decreased according to this sequence: Sediment

> Root system > Leaf system > Stem system (Figure 4).

DISCUSSION

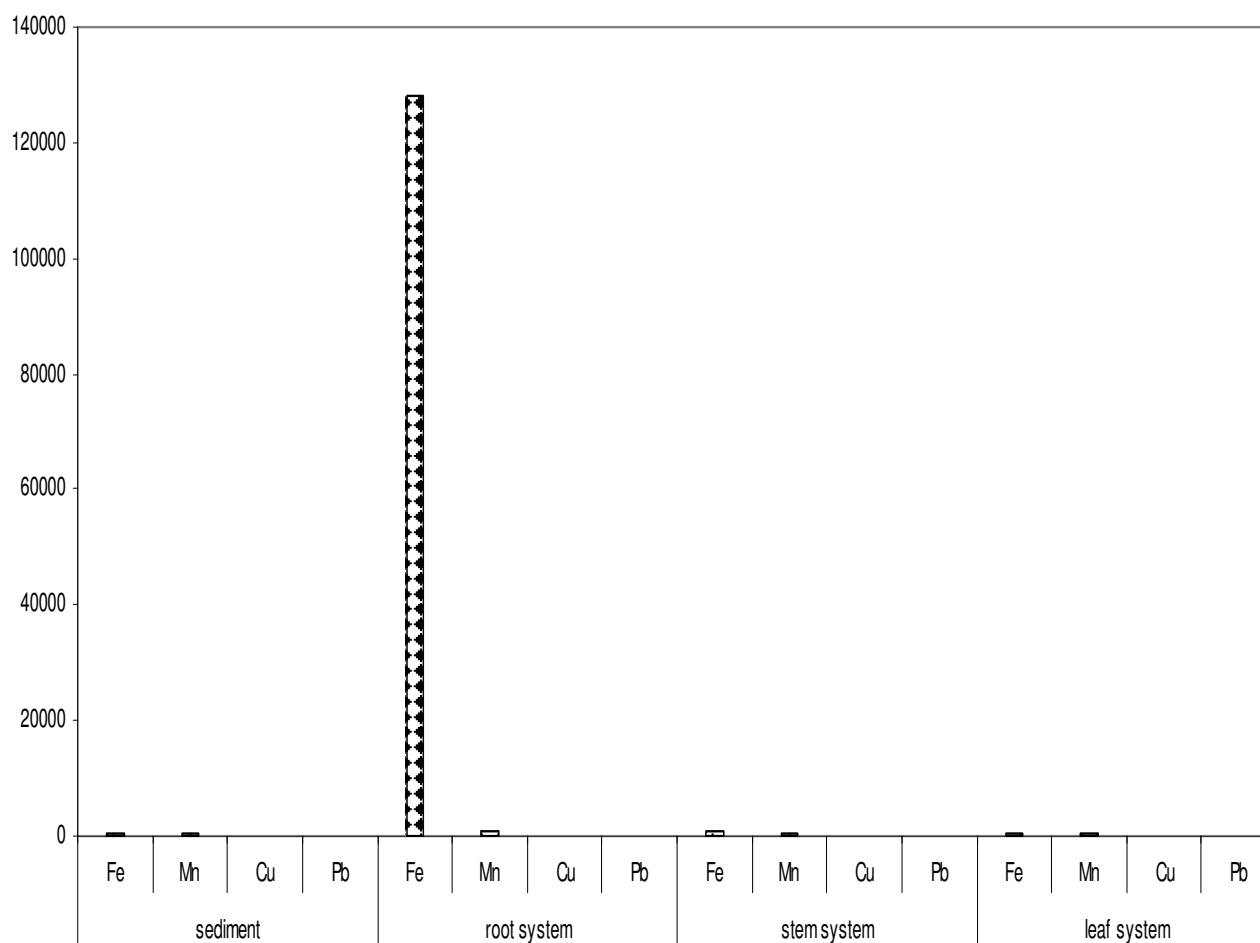
Water and sediments

The element accumulation in sediment is the result of long term exposure, whereas element concentration in water are mainly the result of recent contamination

Table 4. Enrichment coefficient for stems and leaves (ECL and ECS) for five macrophytes

Macrophyte	Fe		Mn		Cu		Pb	
	ECL	ECS	ECL	ECS	ECL	ECS	ECL	ECS
<i>Bidens tripartitus</i>	1.858	1.283	0.604	0.863	0.449	0.266	0.017	0.000
<i>Polygonum amphibium</i>	2.291	5.074	1.632	0.753	0.258	0.264	0.007	0.014
<i>Lycopus europaeus</i>	0.946	3.175	0.884	0.474	0.410	0.432	0.020	0.005
<i>Typha angustifolia</i>	0.594	3.401	4.039	0.826	0.266	0.074	0.090	0.000
<i>Typha latifolia</i>	0.778	2.398	1.073	0.486	0.414	0.293	0.142	0.121
Mean	1.294	3.066	1.646	0.680	0.360	0.266	0.055	0.028

ECL, Enrichment coefficient for leaf = leaf/sediment; ECS, enrichment coefficient for stem = stem/sediment.

**Figure 4.** The mean concentration (mgkg⁻¹ dry weight) of four metals in sediment and parts of aquatic plants.

(Baldantoni et al., 2005).

Result of this study showed that the concentrations of metals were far higher in the sediment than in the lake water. This study is in agreement with previous findings of some researchers (Samecka-Cymerman et al., 2001; Demirezen and Aksoy, 2006; Brankovic, 2007; Pajevic et al., 2008; Brankovic et al., 2010).

The concentration of some elements in the water was mainly below the limit of detection, probably due to sedimentation processes which occurred, where less soluble forms are accumulated in the suspended or sedimented phases. In addition, elements are also absorbed by plankton which can accumulate elements relatively rapidly from water (Chapman, 1992).

Sediment is the most important reservoir or sink of trace elements and other pollutants in aquatic environments, so rooted aquatic macrophytes and other aquatic organisms can take up these pollutants (Mazej and Germ, 2009). Abiotic factors such as organic matter content, pH, nutrients concentration in sediment and water, redox potential, water hardness, light, microbial activity and physical factors are all very important in trace element distribution in water and sediment, and hence their availability to aquatic macrophytes (Guillizzoni, 1991).

Macrophytes

An organism is expected to reflect environmental pollution if it has the ability to take up elements proportionally to their concentration in the environment (Ravera et al., 2003). This is more likely to occur in organisms with little capacity for discriminating between different elements, which are therefore accumulated independently from the organism's physiological needs. In this study, this is exemplified by the high concentrations of investigated elements which were accumulated by both species of the genus *Typha* (*T.angustifolia* - Fe and Mn; *T.latifolia* - Cu and Pb). According to Sawidis et al. (1995), great differences in heavy metal bioaccumulation can be observed within different species of the same genus, under the same environmental conditions. Therefore, metal uptake does not follow physical levels, but it is regulated by plant organism via physiological mechanism.

Gupta and Sinha (2007) reported that the process of metal uptakes and accumulation by different plants depends on the concentration of available metals in soils, solubility sequences and plant species. However, comparison of metal content in macrophytes is often difficult because of the difference in the age of plants and presence of pollution sources during the time (Vardayan and Ingole, 2006).

The C.F. may be calculated when in an organism the concentration of a certain element is or is not at equilibrium level with that in the water; the first case is described as the "real C.F." or "C.F. at equilibrium", the second is the "observed C.F." (De Bortoli et al., 1968). When the C.F. value is at equilibrium, the releasing rate of the pollutant from the organism is equivalent to the in taking rate and, consequently, the pollutant concentration in the organism is fairly constant. This may occur if the pollutant concentration in the water is constant over time and the organism is in a physiological steady state.

The values for C.F. obtained in this study agrees with previously reported data (Ravera et al., 2003; Kumar et al., 2006, 2007, 2008).

Iron, directly or indirectly, is involved in many life processes of plants: Chlorophyll biosynthesis, photosynthesis, respiration, fixation of elemental nitrogen, nitrate and nitrite reduction, metabolism of carbohydrates

and in different redox systems. However, high concentrations of this metal may result in oxidative stress for plant (Bienfait, 1988). According to Allen (1989), 40-500 mgkg⁻¹ and Markert (1992), 5-200 mgkg⁻¹ concentrations of Fe are considered as toxic to plants. However, in this study, the Fe concentrations found in some of the investigated plants (genus *Typha* and *Polygonum*) were much higher than the previous cited. These results are in accordance with other authors (Aksoy et al., 2005; Carranza-Álvarez et al., 2008; Brankovic et al., 2010). Also, Alberts and Camardese (1993) reported that concentration of metals in plants can be more than 100000 times greater than in associated water.

Mn is an essential element for plants necessary in many redox enzymatic processes and in photosynthesis (Memon et al., 2001; Carranza-Álvarez et al., 2008). Mn has a range between 20 and 300 mgkg⁻¹ in most plants, while its level may be as high as 1500 mgkg⁻¹ without harm to some plant (Pais and Jones, 2000). On the other hand, according to Allen (1989), 50-500 mgkg⁻¹ Mn concentrations are considered as toxic to plants. Markert (1992) reported that Mn over 700 mgkg⁻¹ concentration is toxic for plant. The results of this study indicated that species *Bidens tripartitus*, *T.angustifolia* and *P.amphibium* can be considered for Mn as bioaccumulators due to the fact that concentrated Mn in their tissues in levels are higher than its normal range in plants.

Kabata-Pendias and Pendias (2001) reported that Cu levels of various plants from unpolluted regions in different countries changed between 2.1 and 8.4 mgkg⁻¹. According to the results of our study, concentrations of Cu in *Bidens tripartitus* and *L.europaeus* were higher than these mentioned concentrations. This means these plants have a great tolerance to high Cu concentration and Cu can be excessively accumulated in the tissues of these species. The higher concentration of Cu in plants may be caused by using CuSO₄ for water prevention of blooming by blue-green algae (Cyanobacteria).

Kabata-Pendias and Pendias (2001) reported that Pb contents of plants grown in uncontaminated areas varied in between 0.05 and 3.0 mgkg⁻¹. In our study, the Pb concentrations found in *T.latifolia* were much higher than previous cited (31.230 mgkg⁻¹ dry weight), and depend on the plant organ. Carranza-Álvarez et al. (2008) also reported that Pb concentration ranged from 10 to 25 mgkg⁻¹, and the maximum accumulation of Pb was detected in roots. In addition, Pb is considered as toxic to plant tissues at 30-3000 mgkg⁻¹ and was found in the roots of most aquatic plants, higher in roots compared to other parts by factor of 2 (Liu et al., 2007; Carranza-Álvarez et al., 2008). The difference might be due to air pollution by exhaust gases emitted from traffics (Demirezen and Aksoy, 2004).

The results our study exhibited different heavy metal concentration in aquatic plants, depending on the plant organ. Root of macrophytes absorbs heavy metals from the sediments and accumulates high concentration

(Baldantoni et al., 2004; Uphadhyay et al., 2007). Similarly, our findings revealed the high accumulation of investigated metals in roots of both species genus *Typha*. The stems and/or leaves of aquatic plants accumulated lower concentrations of trace elements than root, which is well substantiated with the findings of Baldantoni et al. (2005).

Transfer factor can be used to estimate plant's potential for phytoremediation purpose. The transfer factor of *T.angustifolia* for Mn is 1.329 and indicates efficient way of transportation of Mn from root and its accumulation in leaf. Baker (1981) and Zu et al. (2005) reported that TLFs higher than 1.0 were determined in metal accumulator species, whereas TLFs was typically lower than 1.0 in metal excluder species. The TLFs higher than 1.0 indicated an efficient ability to transport metal from root to leaf, most likely due to efficient metal transporter system of plants (Zhao et al., 2002), and probably sequestration of metals in leaf vacuoles and apoplast (Last et al., 2000). The vacuole is generally considered to be the main storage site for metals in yeast and plant cells, and there is evidence that phytochelatin-metal complexes are pumped into the vacuole (Gratão et al., 2005). It was reported that plants also have the ability to hyperaccumulate various heavy metals by the action of phytochelatins and metallothioneins, forming complexes with heavy metals and translocate them into vacuoles (Suresh and Ravishankar, 2004).

The ECR shows value of elements concentrated in root. *T.angustifolia* and *T.latifolia* had higher enrichment coefficients calculated for selected elements in the roots, than in the leaves and stems, except for Mn. This situation means that the root of both species have an important capacity in accumulation of metals. According to Dunbabin and Bowmer (1992), emergent plants influence metal storage indirectly by modifying the substratum through oxygenation, bufferin, pH and adding organic matter. With respect to this results, it can also be emphasized that species of the genus *Typha* concentrate Fe in theirs roots in the highest values. These results agrees with some reported data (Aksoy et al., 2005; Carranza-Álvarez et al., 2008; Brankovic et al., 2010).

Enrichment coefficient for the leaf (ECL) is a very important factor, which indicates phytoremediation of a given species (Zhao et al., 2003). Some investigated plants in our study had ECL higher than 1, that indicate a special ability of these plants to absorb and transport metals from sediment and then store them in their above-ground part (Baker et al., 1984; Brown et al., 1994; Wei et al., 2002). Plant uptake of elements by leaves becomes more important when the element concentrations in the surrounding environment are high (Guilizzononi, 1991).

Because of the fact that species *P.amphibium* had enrichment coefficients for Fe in the leaf and stem higher than 1, it can be concluded that this species stored Fe in its above-ground parts.

Overall study reflects the transport mechanism of metals from abiotic environment (soil) to biotic environment (macrophytes), and their accumulation in various parts of aquatic plants. The transport mechanism and accumulation pattern of investigated heavy metals (mean concentration) can be generally presented by Kumara et al. (2006) as follows: Sediment > Root system > Stem system > Leaf system. Our study established some different transport mechanism and accumulation pattern for each investigated heavy metals.

Distribution of the elements among plant organs depends on their mobility. It is probable that plants translocate the essential trace elements (Mn, Cu) from the roots into the above-ground tissues for metabolic use, and no pathways for the transport of toxic trace elements (Cr, Ni, or Pb) to these tissues were found (Cardwell et al., 2002; Kumar et al., 2006; Vardanyan and Ingole 2006). It's likely protective mechanisms prevent toxicants from penetrating into the aboveground plant parts. Some toxic elements can be accumulated in a non-dangerous form in organisms provided with detoxification mechanisms, such as the production of metal binding thioneins or calcium phosphate granules (Ravera et al., 2003).

Having compared all our results, it can be concluded that Fe was concentrated and partly accumulated in roots, but some of its amount was transferred and accumulated in lower concentration in the stem and leaf of plants. The lowest concentration of Fe was in leaves, that transfer factor also confirmed. Cu and Pb were primarily accumulated in the root, in order to protect above-ground plant parts from harmful effects of metals. The amount of Cu and Pb was moved to leaves, which was deposited in vacuoles or apoplast, in this way protecting the leaves. Mn is with the highest concentration in sediment and it is translocated from root to leaves, where it was accumulated in the highest level.

Conclusion

This study was carried out on five species of aquatic macrophytes, with the aim to determine the capacity for accumulation of four metals (Fe, Mn, Cu and Pb), that is important for bioindication, bioremediation and bio-monitoring of aquatic ecosystems.

The results showed that concentrations of all investigated metals were higher in sediment than in water. The mean concentrations of investigated elements in macrophytes had next order: Fe > Mn > Cu > Pb, and depended on the plant organ and species. The highest concentration of Fe and Pb were recorded in root of *T. latifolia*. As for Mn and Cu, theirs concentrations were higher in stems and leaves in different investigated species. These results showed that the aquatic plants possess different accumulation ability for selected metals. The results obtained indicate important role of macrophytic vegetation in aquatic ecosystems, and confirm

presumption that chemical analysis of test-species can give very important picture of ecological status of the investigated aquatic ecosystem. The potential of remediation could be enhanced by combination with several different species of macrophytes to develop a cleaner, more economic and efficient way in removing pollutant from the environment.

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