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ZINC AND LEAD IN AQUATIC PLANTS AND BOTTOM SEDIMENTS OF ANTHROPOGENIC RIVERS

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Abstract

The aim of the study was to assess contamination of bottom sediments with heavy metals (lead and zinc) and its influence on the dominant macrophytes in selected four Polish anthropogenic rivers. Due to metal concentration, the sediments were classified in terms of their purity by three criteria: geochemical criterion, LAWA classification and ecotoxicological criterion. The studies revealed that tested macrophytes (Common Reed and Yellow Iris) were characterized by low and very low accumulation coefficient translocation factors of heavy metals. Common Reed was the plant which, to the greatest extent, accumulated heavy metals and therefore it was proposed as an indicator of lead and zinc contamination of river sediments. Heavy metals were mainly accumulated in roots and were not transported to their shoots as evidenced by very low translocation factors. Yellow Iris accumulated heavy metals to a lesser extent than Common Reed, however, it showed higher translocation factors of these metals. Zinc was preferentially collected by both plants in comparison with lead, as confirmed by higher translocation factors for zinc.

Streszczenie

Celem pracy była ocena stopnia zanieczyszczenia osadów dennych metalami ciężkimi (ołowiem i cynkiem) oraz ich wpływu na dominujące makrofity w wybranych czterech przekształconych antropogenicznie rzekach w Polsce. Ze względu na stężenie metali osady rzeczne zostały sklasyfikowane pod kątem ich czystości według trzech kryteriów: kryterium geochemicznego, klasyfikacji LAWA i kryterium ekotoksykologicznego. Badania wykazały, że badane makrofity (trzcina pospolita i kosaciec żółty) charakteryzowały się niskimi i bardzo niskimi współczynnikami akumulacji i translokacji metali ciężkich. Trzcina pospolita to roślina, która w największym stopniu akumulowała metale ciężkie i dlatego została zaproponowana, jako wskaźnik stopnia skażenia osadów rzecznych ołowiem i cynkiem. Metale ciężkie gromadziły się głównie w korzeniach i nie były transportowane do pędów, o czym świadczą bardzo niskie wartości współczynników translokacji. Kosaciec żółty akumulował metale ciężkie w mniejszym stopniu niż trzcina pospolita, jednakże w tym przypadku zaobserwowano wyższe współczynniki translokacji metali. Cynk był preferencyjnie pobierany przez obie rośliny w porównaniu do ołowiu, co potwierdzono wyższymi wartościami współczynników translokacji.

Keywords: **Bottom sediments; Heavy metals; Phytoaccumulation; Translocation; Macrophytes.**

1. INTRODUCTION

Contamination of aquatic environment by heavy metals has become a serious concern in a developing world. Heavy metals, unlike organic pollutants, are persistent in nature and cannot be biologically destroyed. They can only be transformed from one oxidation state or organic compound to another.These metals are released from variety of sources such as mining, urban sewage, smelters, tanneries, textile industry and chemical industry. Heavy metals are highly toxic to aquatic plants and animals as well as and are not easily removed from the environment.

Bottom sediments play an important role in deposition of pollutants released into aquatic environment. In connection with the ability to adsorb and absorb pollutants, sediments are often referred to geosorbents of contaminants in water [1, 2, 27, 33]. Both biomonitoring of water and bioindication are based on the relationship between concentrations of compounds in organisms and concentrations of these compounds in water. The composition of surface water is shaped by many processes, including the exchange of substances in the system: air – water – sediment – living organisms. To obtain reliable information on concentration of pollutants in water, the content of analytes in bottom sediments, as a valuable tool in the environmental research, should also be controlled [29, 34].

Even if water quality improves, contamination deposited in the bottom sediments may still be present. Due to this phenomenon it is possible to trace the history of pollution of the river basin. In aqueous environment heavy metals can be present as: free ions, hydrated ions, organic and inorganic complexes, compounds with insoluble organic and inorganic molecules (hydroxides, carbonates, sulphates, chlorides, metal ions) [13]. These forms are relatively in constant equilibrium, which may, however, be impaired by changing physicochemical conditions in a watercourse [4, 9]. This leads to a secondary pollution of the aquatic environment [8, 32].

One of the methods to assess ecological state of aquatic ecosystems, including the content of heavy metals in rivers, is to determine concentration of these elements in aquatic plants [6, 27]. The possibility of precise analysis and assessment of pollution of sediments is due to the presence of macrophytes – aquatic plants associated with the ground. Some of them are able to accumulate considerable amounts of heavy metals. Literature data report that these plants can accumulate heavy metals 100 000 times more than in the associated water [5, 26]. Thanks to this feature macrophytes are often more useful in the environment controlling than direct analysis of water and sediments [18]. They can also be used in heavy metal removal from a variety of sources.

Literature data indicate [23], there is a clear tendency to accumulate certain trace elements in plants. It is formed in the following way:

- cadmium – a high degree of accumulation,
- zinc, copper and lead –an average degree of accumulation,
- manganese, chromium and nickel – a low degree of accumulation,
- iron – shows no clear tendency to accumulate.

The aim of the study was to determine zinc and lead concentration in bottom sediments in selected rivers and its influence on translocation factors and phytoaccumulation coefficients of these metals in dominant macrophytes. The relationship between heavy metals concentration in bottom sediments and in various organs of aquatic plants was also analysed.

2. MATERIAL AND METHODS

2.1. Sampling area and measuring points

In the research the measuring stations were selected on the base of the previous analyses of heavy metal concentration in water, carried out by the Polish Geological Institute under the State Environmental Monitoring. At the selected points concentration of zinc and lead exceeded normative values (Table 1). The study was conducted on four rivers (the Bierawka, the Gostynia, the Przemsza, the Vistula). The Bierawka was chosen based on the literature data [11].

2.2. Characteristics of the rivers

The Bierawka – the total length is 60.5 km and the basin area of 380.45 km^2 (Czajkowska, 2008). It is characterized by a large number of tributaries and it is also periodically supplied with snowmelt waters after heavy rainfalls. The river basin is also characterized by a network of ditches and canals that discharge wastewater from towns, villages and also from industrial plants located in this area. Pollution of the Bierawka basin is affected by emission of dust and gas related to the production in the nitrogen factory and exploitation of mineral resources. Boilers in households and small production and service located in the area are also important. Contaminated air masses flowing in from neighbouring industry are another source of pollution. The river water quality is affected by industrial and municipal landfill wastes, industrial resources landfills as well as disordered water and wastewater management in rural areas. Five coal mines are also located there [11].

The Gostynia – the length is 31.2 km and the catchment area of 336.8 km^2. It flows through industrialized areas. The river is affected by pollution from the

Table 1.
Measuring points

sampling point	longitude [°]	latitude[°]	dominant plant species
The Bierawka	18.634343	50.196518	Common Reed (*Phragmites australis*), Yellow Iris (*Iris pseudacorus*)
The Gostynia	19.10667	50.06147	Common Reed (*Phragmites australis*), Yellow Iris (*Iris pseudacorus*)
The Przemsza	19.23875	50.16147	Common Reed (*Phragmites australis*) Yellow Iris (*Iris pseudacorus*)
The Vistula	19.234761	50.064577	Common Reed (*Phragmites australis*), Yellow Iris (*Iris pseudacorus*)

energy power station, the coal mines, their on works and local highly polluted cities. The large pollutant loads are carried along with a stream which shows exceeded concentrations of total phosphorus, phosphate and zinc. The analysis of the Gostynia quality revealed high concentrations of chlorides up to 7448 mg·L^{-1}, dissolved substances amounting to 15011 mg·L^{-1} and certain amounts of radioactive radium. It indicates that the river is supplied with saline waters from coal mines.

The Przemsza – the length is 87.6 km and the catchment area of 2,121.5 km^2. This area is characterized by high anthropopressure. Potential sources of contamination are: the works of mechanical processing of coal, the factories of steel and glass and the two energy power plants. Large pollutant loads of non-ferrous metals (mainly lead and silver) derived from the factory operated in the distant past are also noted there.

The Vistula – the Vistula is the longest river of total length 1047 km and the catchment area of 194.42·10^3 km^2. The water quality of the river is mainly influenced by municipal and industrial sewage and mine waters. There are many industrial plants located in the areas through which the river flows. Its tributaries are also heavily contaminated.

2.3. Sampling and analysis of sediments

Fresh bottom sediments were collected in six replicates once a month for 12 months. They were collected from a depth of 10 cm from sediment surface using a small trowel and packed in a plastic zip locked bags for transport to the laboratory. The samples were stored at 4°C. The samples were dried overnight by placing it into aluminum trays (150×170 mm) in a fan forced oven at 80°C and homogenized by grinding with mortar and pestle. Zinc and lead analyses were made with the usage of apparatus 880 SpectrAA with flame atomization. The obtained results present the average concentration values obtained in the study period.

2.4. Sampling and analysis of macrophytes

The tested plants are so-called helophytes which collected pollutants mainly through the roots and were analysed from this point of view. The study assessed the concentrations of metals in individual parts of plants as well as in sediments, which allowed to determine whether and to what extent plants take impurities and whether these pollutants are transported to the upper parts of plants or accumulate in their roots. Based on the conducted studies, translocation and accumulation coefficients were calculated and the analysis of the obtained research results in this aspect was carried out. It is very important to understand these dependencies from the point of view of heavy metals removal from the environment. Young plants – 1 year old – were taken for the research. Therefore the time of exposure of plants to pollution was similar.

Plants were sampled at the end of the growing season in November. In this way, it was possible to examine how much contaminants a plant could collect within 1 year. Different plants were deliberately selected to check which plant, in the smallest, and which to the greatest extent cumulates pollutants and where these pollutants are accumulated.

The samples of dominant macrophytes (10 plants of each species in five replicates) were collected from the same measurement points. The purpose of plant sampling in November was to answer the question what amount of metal and in what parts of a plant has been accumulated throughout the growing season. Immediately after sampling, the plants were placed in bags with a zipper. Each bag was labelled by a description of a species of plant, a date and an exact place of sampling. Plants were carefully washed using tap water then distilled water to remove all the debris. Plants were then separated into roots and shoots. The washed samples were dried of adherent water using absorbent paper and stored in a plastic zipped bag and refrigerated at 4°C for 1 week. Samples were then cut into small pieces, placed in aluminum trays (145×165 mm) and dried to a con-

Table 2.
Acceptable content of zinc and lead in sediments (LAWA classification)

metal	Purity class						
	I	I-II	II*	II-III	III	III-IV	IV
	Unpolluted	Unpollut./ moder. polluted	Moder. polluted	Moder. polluted/strongly polluted	strongly polluted	strongly/very strongly polluted	very strongly polluted
	[mgkg^{-1} d.m.]						
zinc	≤100	≤200	≤400	≤800	≤1600	≤3200	>3200
lead	≤25	≤50	≤100	≤200	≤400	≤800	>800

* recommended limit value

stant mass in a fan forced oven at 80°C. This temperature was required to remove all the moisture. The temperature could not exceed 80°C to prevent from thermal decomposition and hence reduction of the dry weight [10].

Such prepared samples of 0.15 g (diameter <1 mm) were weighed and placed in teflon vessels. After injection of 3 cm^3 of nitric acid (V) into the samples, they were mineralized in an open system on a hot plate. After evaporation of the acid, the samples were again poured over with 3 cm^3 of 65% HNO_3 and mineralized in a closed system, in a microwave oven MLS-1200 MEGA Milestone for 6 minutes (1000W). Mineralized samples were quantitatively transferred to flasks with a volume of 50 cm^3 and filled with distilled water. The prepared samples were assayed for heavy metals by atomic absorption spectrometry technique. Zinc and lead concentrations were performed in six replicates. Plant samples were analysed with the apparatus SpectrAA Zeeman with electrothermal atomization. The presented results show an average metal concentration of 10 samples for each plant species.

2.5. Criteria of sediments evaluation

Evaluation of the quality of sediments was carried out on the basis of three criteria:

- LAWA (Länder-Arbeitsgemeinschaft Wasser) classification for sediment quality – consists of four main and three sub-classes based on data for seven heavy metals, 28 organic pollutants, nutrients, salts and 11 parameters [19] (Table 2),
- geochemical criteria for assessing the degree of contamination of sediments with respect to geochemical background, or the content of elements found in sediments in natural conditions [7] (Table 3),
- ecotoxicological criterion for assessing the degree of influence of polluted sediments on aquatic organisms [22] (Table 4).

Table 3.
Geochemical evaluation criteria of bottom sediments of rivers and lakes [7]

metal	uncontaminated sediment [mg kg^{-1} d.m.]	moderately contaminated sediment [mg kg^{-1} d.m.]	contaminated sediment [mg kg^{-1} d.m.]
zinc	200	500	1000
lead	30	100	200

Table 4.
Ecotoxicology criteria for assessment of pollution of bottom sediments of rivers and lakes [22]

metal	TEL (Threshold Effect Level) [mg kg^{-1} d.m.]	PEL (Probable Effect Levels) [mg kg^{-1} d.m.]
zinc	123	315
lead	35	91

TEL (threshold effect level) and PEL (probable effect level) values were also calculated. TEL determines the content of the element or chemical compound, above which toxic effects on aquatic organisms may be observed. PEL determines the concentration of the element, above which toxic effects on aquatic organisms are frequently observed. Similarly to the geochemical criterion the sediment is considered to be toxic to aquatic organisms even in the case when only one element concentration exceeds the critical PEL value [22].

The lower value, referred to as the threshold effect level, represents the concentration below which adverse biological effects are expected to occur rarely. The upper value, referred to as the probable effect level, defines the level above which adverse effects are expected to occur frequently.

2.6. Translocation factor (TF) and phytoaccumulation (PC) coefficient

In order to evaluate the direction of movement and the degree of accumulation of metals in plants, translocation factor (TF) and phytoaccumulation

(PC) coefficient were calculated. Translocation factor allows to specify metal mobility in the studied plants. TC is calculated as a ratio of metal concentration in shoots of plants to metal concentration in roots. Low values of TF indicate that most of the metal was accumulated in roots [21]. Translocation from shoot to root was measured by TF which is calculated as follows:

$$TF = C_{shoot}/C_{root}$$

where, C_{shoot} and C_{root} are metal concentrations in shoot (mg·kg^{-1}d.m.) and root of plant (mg·kg^{-1}d.m.), respectively. TF>1 represents that translocation of metals effectively was made to shoot from root of a plant [14, 35].

PC is calculated as a ratio of metal content in different parts of plants to the amount of sediment. The results are interpreted as follows:

PC ≤ 0.01 – accumulation does not occur

PC ≤ 0.1 – weak degree of accumulation

PC ≤ 1.0 – average degree of accumulation

PC > 1.0 – intense degree of accumulation [21].

Statistical analysis of the results included the calculation of the arithmetic mean and standard deviation. To verify the distribution normality the Shapiro-Wilk test was applied. The significance of differences between individual samples was assessed using Student's t-test. Differences were considered statistically significant if $p<0.05$. Statistical analysis was performed using Statistica 10 software. In order to investigate the relationship between the degree of accumulation of metals in plants (their above-ground and underground parts) and the concentration of metals in bottom sediments, Pearson's test was carried out.

3. RESULTS AND DISCUSSION

3.1. Concentration of lead and zinc in bottom sediments

The results of the study show the diversity of concentration of lead and zinc (Table 5) in bottom sediments depending on a sampling point.

Table 5.
Concentration of lead and zinc in bottom sediments

sampling point	lead concentartion [mg·kg^{-1}d.m.]	zinc concentration [mg·kg^{-1}d.m.]
The Bierawka	80.39±10.2	548.1±10.96
The Gostynia	58.99±8.6	224.06±1.181
The Przemsza	1623.82±17.28	4356.26±104.928
The Vistula	866±12.56	649.5±59.37

The highest concentration of lead was found in sediments of the Przemsza and it was 1623.82 mg·kg^{-1}d.m., while the lowest in sediments of the Gostynia (58.99 mg·kg^{-1}d.m.) (Table 5). According to the literature [20] the natural content of lead in sediments, except for the areas in which there is its natural increase resulting for example from the presence of its ores (e.g. Galena), is noted at 45 mg·kg^{-1}d.m. Bojakowska and Sokołowska [7] reported that lead content in uncontaminated sediments; generally does not exceed 30 mg·kg^{-1}d.m.Variability of lead concentration in bottom sediments substantially coincides with the geochemical background of this element in soils, and the Geochemical Atlas of Poland indicates that the arithmetic mean for lead is 68 mg·kg^{-1}d.m. [20], while for Europe 38.6 mg·kg^{-1}d.m. [28]. Based on the obtained results at all measuring points all the above mentioned values were exceeded. According to LAWA classification, lead content in sediments of the Przemsza and the Vistula rivers classified them into IVth class of purity, which indicated a significant load of lead in the environment, while Pb concentrations in the Bierawka and the Gostynia classified them into IInd class (Table 2, Table 5).

The highest concentration of zinc, similarly to lead, was found in sediments of the Przemsza and it was 4356.26 mg kg^{-1}d.m., the lowest value was noted for sediments of the Gostynia (224.06 mg·kg^{-1}d.m.) (Table 5). The natural limit of zinc in sediments of Polish rivers is 220 mg·kg^{-1}d.m. [20]. Analysing the arithmetic mean values of zinc content in sediments in Poland amounting 247 mg·kg^{-1}d.m. and in Europe 120 mg kg^{-1}d.m., it is clear that significantly higher contents of this element were measured in the study. The analysis of the achieved results indicates that Zn concentrations in all studied points were higher than the accepted limit background. High concentrations of zinc in the studied rivers were probably connected with a place of sampling (urban areas, large industrial cities).

According to LAWA classification (Table 2) [19] zinc content in the Przemsza corresponds collected sediments to the IVth class of purity, which indicates a very high contamination of environment. Concentration of zinc in sediments of the Bierawka and the Vistula classified them into the II-IIIth class of purity (moderate or strong contaminated), and the Gostynia zinc concentration matches its sediment to the IInd class of purity (moderately polluted) (Table 2, Table 5).

Taking into account acceptable concentrations of lead and zinc determined by the geochemical

Table 6.
Comparison of the results of geochemical assessment

sampling point	geochemical evaluation based on the studies	geochemical evaluation of the Geological Institute
The Bierawka	contaminated sediment	*
The Gostynia	moderately contaminated sediment	contaminated sediment
The Przemsza	heavily contaminated sediment	heavily contaminated sediment
The Vistula	contaminated sediment	moderately contaminated sediment

*the object is not enclosed in monitoring of the Geological Institute

Table 7.
Comparison of the results of ecotoxicological assessment

sampling point	ecotoxicological evaluation based on the studies	ecotoxicological evaluation of Polish Geological Institute in 2011
The Bierawka	sediment often harmfully influencing living organisms	*
The Gostynia	sediment occasionally harmfully influencing living organisms	sediment occasionally harmfully influencing living organisms
The Przemsza	sediment often harmfully influencing living organisms	sediment often harmfully influencing living organisms
The Vistula	sediment often harmfully influencing living organisms	sediment often harmfully influencing living organisms

*the object was not enclosed in monitoring by the Geological Institute

Table 8.
Lead concentration in different parts of plants

sampling point	Common Reed (root) [mg·kg^{-1}d.m.]	Common Reed (steam) [mg·kg^{-1}d.m.]	Yellow Iris (root) [mg·kg^{-1}d.m.]	Yellow Iris (steam) [mg·kg^{-1}d.m.]
The Bierawka	10.22±1.168	0.99±0.138	2.3±0.460	1.38±0.144
The Gostynia	5.67±1.066	1.94±0.207	1.5±0.358	0.78±0.101
The Przemsza	186.8±6.771	22.6±1.648	41.78±2.962	24.14±3.792
The Vistula	112.6±7.843	9.86±1.114	18.6±1.442	8.6±0.844

Table 9.
Zinc concentration in different parts of plants

sampling point	Common Reed (root) [mg·kg^{-1}d.m.]	Common Reed (steam) [mg·kg^{-1}d.m.]	Yellow Iris (root) [mg·kg^{-1}d.m.]	Yellow Iris (steam) [mg·kg^{-1}d.m.]
The Bierawka	148.7±17.815	14.92±1.635	21.92±1.687	16.48±1.699
The Gostynia	111.14±18.898	61.49±7.339	11.2±1.247	8.88±0.295
The Przemsza	860.9±104.298	386.7±61.957	185.78±22.770	150.8±11.658
The Vistula	144.2±31.909	16.8±1.291	28.24±2.811	20.9±3.299

criterion [7] (Table 3, Table 5), sediments of the Przemsza are highly contaminated The concentrations of Zn and Pb in sediments of the Bierawka and the Vistula classify them as contaminated sediments, while bottom sediment of the Gostynia as moderately polluted. Comparing these results with studies by the Geological Institute in 2011, it was noted that pollution of the Gostynia decreased, of the Vistula increased and the degree of pollution of the Przemsza was unchanged (Table 6).

On the basis of the ecotoxicological criterion (Table 4, Table 5) it was found that concentrations of heavy metals in all selected sediments were considered to be toxic to aquatic organisms. The Gostynia sediment, because all threshold concentrations were exceeded, was classified as occasionally harmful to living organisms. Comparing these results with ecotoxicological assessment carried out by the Polish Geological Institute in 2011, the toxic effect of heavy metals on living organisms in the Gostynia basin decreased. However, the increased risk of adverse impacts of lead and zinc on living organisms was observed in the Vistula (Table 7).

3.2. Concentration of lead and zinc in plants

The concentration of lead and zinc in various parts of plants varied depending on the place of sampling and tested plant species (Table 8, Table 9). Pb content in the roots of macrophytes ranged from 1.5÷186.8 mg kg^{-1}d.m. (Table 8) and the concentration of lead in shoots was in the range of 0.78÷24.14 mg kg^{-1}d.m. The highest concentration of lead in roots was noted for Common Reed collected from the Przemsza, while the highest concentration of lead in shoots was noted for Yellow Iris which was collected from the Przemsza. The lowest concentration for this species was noted at the measuring point located in the Gostynia.

According to the literature data [15] natural lead content in plants is in the range of 1÷1.5 mg kg^{-1}d.m. The obtained results (Table 8) indicate that in most cases concentration of lead was exceeded. Differences in the amount of lead accumulated in plants depended on its concentration in sediments and a plant species.

The study showed that the degree of accumulation of lead depended on a plant species. Common Reed accumulated more lead than Yellow Iris. The roots of the plants accumulated more Pb than the shoots, for example Pb concentration in roots of Common Reed. Roots of Common Reed accumulated approximately 4 times more lead than the roots of Yellow Iris (Table 8, Table 9). Similar relationships were reported from other studies [26, 30, 31]. This phenomenon is closely linked to defense mechanisms of plants and their adaptive capacity to live in unfavorable conditions [23]. The macrophytes of high biomass fibrous root and broad leaves can absorb higher concentrations of heavy metal. Higher accumulation of heavy metals by Common Reed may be attributed to their luxuriant growth in heavy metal and nutrient rich media, greater biomass accumulation and preferential adsorption of metals from medium[26].

The concentration of zinc in different parts of plants was dependent on a sampling point (Table 9).

The highest concentration of zinc in a root and in shoots of plants was noted for – Common Reed collected from the Przemsza. The lowest concentration was noted in a root and steam part of Yellow Iris collected from the Gostynia. According to Kabata-Pendias (2002), the average content of Zn in shoots parts of plants, which were not subjected to pollution, is noted in the range of 10÷70 mg kg^{-1}d.m. Most of the values achieved in the study did not exceed the specified range (Table 9) (except for Yellow Iris collected from the Przemsza – 150.8 mg kg^{-1}d.m. and Common Reed root samples in all rivers and Common Reed shoots collected from the Przemsza). An acceptable concentration of zinc is 150 mg kg^{-1}d.m. The higher values are regarded to reveal probable toxic effects on a plant. Heavy metal accumulation in aquatic macrophytes is known to produce significant physiological and biochemical responses towards the growth of roots, stems and leaves [23, 26]. Accumulation degree of heavy metals in macrophytes noted in the study is in agreement with the results obtained by other researchers [3, 9, 12, 16, 25, 26].

Phytoaccumulation coefficients for lead were low and ranged from 0.009 for the shoots of Yellow Iris collected from the Vistula to 0.13 for Common Reed root collected from the Vistula (Table 10). The obtained values qualify the samples to three phytoaccumulation groups which specify: the lack of accumulation, poor and average degree of accumulation.

Table 10.
Phytoaccumulation coefficients for lead

sampling point	plant	part of the plant	phytoaccumulation coefficient (PC)	accumulation degree
The Bierawka	Common Reed	shoot	0.012	poor
		root	0.127	average
	Yellow Iris	shoots	0.017	poor
		root	0.029	poor
The Gostynia	Common Reed	shoots	0.033	poor
		root	0.096	average
	Yellow Iris	shoots	0.013	poor
		root	0.025	poor
The Przemsza	Common Reed	shoots	0.014	poor
		root	0.115	average
	Yellow Iris	shoots	0.015	poor
		root	0.026	poor
The Vistula	Common Reed	shoots	0.011	poor
		root	0.13	average
	Yellow Iris	shoots	0.009	no accumulation
		root	0.02	poor

Table 11.
Phytoaccumulation coefficients for zinc

sampling point	plant	part of the plant	phytoaccumulation coefficient (PC)	accumulation degree
The Bierawka	Common Reed	shoot	0.027	poor
		root	0.271	average
	Yellow Iris	shoots	0.003	no accumulation
		root	0.04	poor
The Gostynia	Common Reed	shoots	0.274	average
		root	0.496	average
	Yellow Iris	shoots	0.04	poor
		root	0.05	poor
The Przemsza	Common Reed	shoots	0.089	poor
		root	0.197	average
	Yellow Iris	shoots	0.035	poor
		root	0.043	poor
The Vistula	Common Reed	shoots	0.026	poor
		root	0.222	average
	Yellow Iris	shoots	0.03	poor
		root	0.04	poor

Low phytoaccumulation coefficients of heavy metals may arise both from a short bioavailability of this metal for the studied species. In all cases PC calculated for the root part was higher than PC calculated for shoots of the plant. Similar results were observed by Mishra and Tripathi (2008), Samecka-Cymerman and Kempers (2007) and Skorbiłowicz (2015).

Phytoaccumulation coefficients calculated for zinc were slightly higher than for lead and noted from 0.026 for Common Reed in its shoots in the samples taken from the Vistula up to 0.496 for Common Reed root taken from the Gostynia (Table 11). The obtained values qualify these samples to three phytoaccumulation groups which specified: the lack of accumulation, poor and average degree of accumulation. Similarly to lead, PC values calculated for root were higher than calculated for shoots of the plants.

Statistical analysis of the results showed significant differences (with probability $p=0.05$) in the uptaking of zinc and lead by the roots of Common Reed for two measuring points: the Bierawka and the Gostynia, while there were no statistically significant differences when collecting these metals by Yellow Iris. However, zinc was more easily uptaken by plants.

Translocation factor (TF) for lead ranged from 0.088 for Common Reed from the Vistula up to 0.578 for Yellow Iris collected from the Przemsza (Table 12). Low TC values show that translocation of lead in the analysed plants was negligible. The reason for this phenomenon could be blocking of apoplastic ion transport or creating of special defence mechanisms [23]. These results are in agreement with Gupta and Sinha (2006), who found that concentration of heavy metals (Fe, Zn, Cr, Mn, Cu, Pb, Ni, Cd) was higher in roots compared with shoots of *Sesamum indicum*. Furthermore, McLaughlin et al. (2000) found a strong correlation between the concentration of Cd and Zn in leaves of two species of *Salix* and their concentration in soil. Also, they found the highest accumulation of Cu, Cr, Pb, Fe, Mn and Ni was in roots.

Translocation factor for zinc was generally higher than for lead. It was noted from 0.117 for Common Reed collected from the Vistula up to 0.812 for Yellow Iris taken from the Przemsza. The relatively low translocation factors for lead indicate that the majority of lead accumulated in the plant was deposited in its roots.

Table 13 presents Pearson correlation coefficient illustrating the relationship between metal concentrations in bottom sediments of the studied rivers and their concentrations in individual parts of plants. Calculation of the correlation coefficient (Pearson) allowed to define a linear relationship between the analyzed variables. It indicated that both zinc and lead, were readily absorbed by plants.

Table 12.
Translocation factors for lead and zinc

sampling point	translocation factor for lead		translocation factor for zinc	
	Common Reed	Yellow Iris	Common Reed	Yellow Iris
The Bierawka	0.097	0.6	0.16	0.752
The Gostynia	0.342	0.52	0.553	0.793
The Przemsza	0.121	0.578	0.449	0.812
The Vistula	0.088	0.462	0.117	0.74

Table 13.
Pearson correlation coefficient

Plant	Correlation	The Bierawka		The Gostynia		The Przemsza		The Vistula	
		Pb	Zn	Pb	Zn	Pb	Zn	Pb	Zn
Common Reed	sediment - root	0.842	0.970	0.970	0.997	0.817	0.607	0.948	0.954
	sediment - steam	0.736	0.948	0.967	0.982	0.798	0.751	0.814	0.867
	root - steam	0.968	0.973	0.988	0.983	0.939	0.970	0.911	0.877
Yellow ris	sediment - root	0.878	0.972	0.983	0.908	0.889	0.851	0.841	0.967
	sediment - steam	0.788	0.958	0.969	0.961	0.803	0.684	0.801	0.828
	root - steam	0.919	0.986	0.996	0.972	0.935	0.876	0.915	0.933

5. CONCLUSIONS

1. Common Reed accumulated heavy metals mainly in roots and they were not transported to their shoots as evidenced by very low translocation factors.
2. Yellow Iris accumulated heavy metals to lesser extent than monocots, however, they showed higher translocation factors of these metals.
3. Zinc was preferentially collected by both plants in comparison with lead, as confirmed by higher translocation factors for zinc.
4. Phytoaccumulation coefficients (PC) of heavy metals in shoots were lower than in roots. Phytoaccumulation of zinc in Common Reed and Yellow Iris roots and shoots was significantly higher than phytoaccumulation of lead.
5. Significant correlation between metal concentration in aquatic plants and sediment was obtained both for Zn and Pb. It suggests that concentration of heavy metals in macrophytes reflects metal concentration in bottom sediments.

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