

THE CONTAMINATION OF BOTTOM SEDIMENTS IN WATER RESERVOIRS IN THE VICINITY OF BANSKÁ ŠTIAVNICA (SLOVAKIA) BY POTENTIALLY TOXIC ELEMENTS

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Abstract: The Štiavnické lakes located in the vicinity of Banská Štiavnica (Slovakia) represent unique, historical engineering works that are part of UNESCO's World Heritage. From the scientific point of view, lake sediments from an area rich in silver, gold, lead, and other metals, which have been mined and processed here for over 1000 years, could become a valuable historical research material. Sediment sampling has been performed according to STN ISO 5667-12. Sediment samples were collected from water reservoirs Bakomi, Rozgrund, and Vindšachta. Potentially toxic elements in sediments were analyzed by AAS spectrometry. The Bakomi water reservoir sediments contained on average (in mg.kg⁻¹): Cd 2, Cu 17, Mn 530, Pb 94 and Fe 27,601. Sediments taken from the Vindšachta area contained on average (in mg.kg⁻¹): Cd 2, Cu 30, Mn 980, Pb 96 and Fe 26,884. The sediment in Rozgrund differed significantly from the sediments of other lakes. The sediments of the Rozgrund area, whose reservoir has not been drained in 270 years, contained on average (in mg.kg⁻¹): Cd 6, Cu 39, Mn 1,471, Pb 205 and Fe 37,786. The concentration profile of sediments was examined to the depth of 42cm, while in one case (Mn in the reservoir sediment) the gradual increase of concentration with depth was observed. Concentration anomalies associated with depth were not detected in the examined metals. Concentration anomalies associated with mining or severe air pollution were not detected in the examined metals.

Key Words: sediments, heavy metals, atomic absorption spectroscopy metode

1. INTRODUCTION

The Banskoštiavnický region is a typical area influenced by long-term mining. The origins of mining activities date back to the Bronze Age. The first written evidence that mentions local mining dates from 1156 CE. By the 14th century, the mines supplied the then Europe-wide production of silver.

In the 18th and 19th centuries, this ore district was not only a significant centre for the mining of high-grade silver and gold ores but also a technologically advanced centre, including water management, in Europe (Bakaljarová & Cígerová, 2003). Aside from abundant precious metal deposits, the deciding factor for mining was water accumulated in the numerous reservoirs concentrated in the vicinity of Banská Štiavnica. The collected water served as the main energy source, as

well as a technological component, in ore extracting and processing.

The effect of mining on the region's environment is truly substantial due to, for example, sulfur-acidic erosion – the oxidation of sulphide minerals (especially pyrite) results in the formation of acids (H₂SO₄). The acidic environment causes additional intense mineral erosion, further acidification and mobilization of various elements. Ore mining around Banská Štiavnica resulted in slag heaps, metallurgical debris, and ponds that have been subject to several studies (Križáni & Andráš 2006; Križáni et al., 2009; Križáni et al., 2007). Other, partly similar, old contaminated sites in Slovakia have also been examined (Andráš et al., 2012; Franková et al., 2012 and Andráš et al., 2008).

From the scientific point of view, lake sediments from this area rich in silver, gold, lead,

and other metals could become a valuable historical research material.

The extraction, treatment and processing of Au-Ag and Pb-Zn-Cu ores in the past resulted in severe air and soil pollution around Banská Štiavnica. Such developments led to high rates of morbidity, mortality, and short life expectancy among the residents of the Banská Štiavnica area. That might have been the stimulus for the building of an original system for the separation of solid pollutants from exhaust gas, the first or one of the first such exhaust gas purification systems in the world. More than 100 years ago on the hill closest to the ore treatment and processing facility in Banská Štiavnica, a tall chimney was built and connected to the sources of pollution by a large ground canal. Due to the slow flow of exhaust gas, gravitational separation of solid particles occurred in the canal. The canal dimensions allowed for unhindered movement of workers who removed the sedimented solids.

The following paper focuses on the observation of potentially toxic elements in bottom sediments of water reservoirs Bakomi, Rozgrund, and Vindšachta, located in the vicinity of Banská Štiavnica (Slovakia). Its aim is to determine the average amounts and concentration profiles of potentially toxic heavy metals (Cd, Cu, Fe, Mn, Pb) in the sediments in order to estimate whether and what measures should be considered when removing bottom sediments, and possibly to determine whether concentration anomalies of some heavy metals occur in the lake sediments as a result of historical pollution.

2. CHARACTERISTICS OF THE LOCATION AND THE SELECTED WATER RESERVOIRS

The research objects are located in a part of Štiavnické vrchy (mountains), a geomorphological unit in Slovakia as a part of the Vnútorne Západné Karpaty subprovince and the Slovenské stredohorie region. The whole area surrounding Banská Štiavnica is affected by more than a thousand years of mining activity. The Bakomi, Rozgrund, and Vindšachta reservoirs are still currently important reservoirs of the whole water system. The whole water reservoir system in Štiavnické vrchy are unique water structures in terms of water collection, mutual connections among individual reservoirs by ditches and water tunnels, and its usable water resource capacity. The building of Bakomi reservoir began in 1736. The building of Vindšachta reservoir began in 1712 (Lichner, 2005, Bakaljarová & Cígerová, 2003). The building of Rozgrund began

after 1741. Up until the end of the 19th century, the water was used for the propelling of ore crushers. Since the beginning of the last century, its water has been pumped into the Veľký Vodarenský reservoir for supplying Banská Štiavnica residents with drinking water (Lichner, 2005).

3. SEDIMENTS AND THEIR SIGNIFICANCE FROM THE ENVIRONMENTAL PERSPECTIVE

From the geochemical perspective, knowledge of the chemical composition of sediments has primarily prospective and environmental significance. It is also highly significant from a water management perspective (the amount and the quality of sediment in the reservoirs, dams, lakes, etc.) (Bodiš & Rapant, 1999).

Sediments, as a carrier medium, represent positive as well as negative environmental sources and can have variable influence on the quality of natural water, soil, biotope, and on humans by means of the food chain.

The character and chemical composition of contaminants in the sediments may be variably inorganic and organic. The ratio between the dissolved and solid contaminants phases depends on the character of input and, consequently, from interactions among individual environmental components. The solid phase which interacts with dissolved natural water components is composed primarily of clay materials, carbonates, quartz, feldspars, accessory minerals, and organic matter. The most common bonding materials are hydrated oxides of iron, manganese, aluminium, clay materials and organic matter.

The granular composition of bottom sediments in the investigated water works in Slovakia generally corresponds with the granular composition in agricultural and forest soils in individual river basins. In most cases, bottom sediments belong among moderately heavy soils (sandy loam and loam) with fraction content lower than 0.01 mm within the 20-45 % range. Due to erosion process laws, sand fractions sediment where river streams enter water works and the smallest clay shares sediment at the water work dam walls. This should be taken into account in the extraction and use of sediments, or their removal.

A number of analytical procedures, criteria, and norms are used in the world for the assessment of sediment quality (Burton, 2002). In Slovakia, potentially toxic elements that may occur in sediments are assessed by:

a) National Council of the Slovak Republic (NC

- SR) Act no. 188/2003 Coll. as amended
- b) Ministry of Environment of the Slovak Republic (ME SR) methodical guideline no. 549/98-2
- c) Ministry of Agriculture of the Slovak Republic (MA SR) Decree no. 508/2004 Coll. as amended
- d) Canadian Sediment Quality Guidelines for the protection of Aquatic Life
- a) National Council of the Slovak Republic Act no. 188/2003 Coll. on the application of sewage sludge and bottom sediments into soil as amended. The law lists the maximum concentration amounts of risk elements in bottom sediments.
- b) ME SR methodical guideline no. 549/98-2 for the risk assessment of stream and water reservoir sediments

The basic concepts for the comparison of the pollutant concentrations in sediments with maximum limits listed in the methodical guideline for dry sediment weight are:

TV (Target Value) permissible risk. As target value approximating unspoiled environment represented by uncontaminated sediment, derived from ecotoxicological tests and representing 1/100 MPC. It sustains a 100% survival of water organisms.

MPC (Maximum Permissible Concentration) maximum permissible risk. It is the maximum permissible concentration of an element in sediment, the exceeding of which leads to unacceptable environmental risk. Values determined in the criteria were set at the level ensuring survival of 95% of all organisms in the ecosystem. It is based on the assumption that at the 95% protection rate of all species of organisms in an ecosystem, the ecosystem can evolve and function without disturbance.

TVd (Testing value) ranges in the MPC and IV interval and can be used when deciding how to handle sediment.

IV (Interventional Value) serious risk. The interventional value represents a high risk for an ecosystem. It is derived from ecotoxicological tests and corresponds to substance concentration levels at which protection of 50% of all species of organisms in the ecosystem is ensured.

The principles and the defined risk levels in an

ecosystem are summarised in table 1.

The overall sediment assessment results are divided into three basic classes according to the effect on ecosystem:

- No effect – the values measured for each chemical element or compound are lower than the limit MPC value listed in appendix no. 1 of the methodical guideline for dry sediment weight
- + Potential risk – the values measured for at least one chemical element or compound range in the interval = or > than MPC to < than IV
- ++ Serious risk – the values measured for at least one chemical element or compound equal or exceed IV.

c) The Ministry of Agriculture of the Slovak Republic Decree no. 508/2004 Coll. from 23 of August, 2004 putting in effect Section 27 of Act no. 220/2004 Coll. on the protection and use of agricultural soils, as amended

In appendix no. 7 of the decree are listed the maximum levels of risk elements in agricultural soils and the methods of their identification by selected indicators. The limit levels are determined for the following soil types:

- A – sandy, loamy-sandy soil.
- B – sandy-loam, loam.
- C – clay-loam, clay.

d) Canadian Sediment Quality Guidelines for the protection of Aquatic Life

Within the sediment quality assessment framework, this norm utilises measured (absolute) levels of individual indicators. Table 2 lists evaluation based on this norm. According to the Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, the corresponding concentrations of substances for TEL and PEL were derived from toxicological information provided by the National Status and Trends Program (modified NSTP) and from Spiked-sediment toxicity test (SSTT).

TEL – Threshold effect level, concentration which, when exceeded, leads to an adverse biological effect. At lower (<TEL) levels the adverse effects occur only rarely.

Table 1. Principles and defined risk levels in an ecosystem

Risk	Limit	Maximum concentration value for survival of organisms (%)	Survival of organisms (%)
Permissible risk	Lower than maximum permissible concentration MPC	MPC (95 %)	95 - 100 %
Serious (high, unacceptable) risk	More than maximum permissible concentration	IV (50 %)	50 - 95 %
Handling sediments			
Testing value	Sediment should be tested when used or stored	TVd (95-50 %)	50 - 95 %

Table 2. Evaluation based on Canadian Sediment Quality Guidelines for the Protection of Aquatic Life

Effect/concentration	< TEL	TEL – PEL	> PEL
Adverse effect	Rarely	Intermittently	Frequently
Adverse effect	< 25%	25 – 50%	> 50%

PEL – Probable effect level, concentration where it is expected that, when exceeded, the adverse affect occurs frequently.

Hitherto, there is not enough data from testing toxicity by the SSTT method. Therefore, where such testing has not been conducted, only NSTP results are used and instead of TEL, are referred to as ISQG (Interim Sediment Quality Guidelines).

4. SAMPLES AND METHOD

Bottom sediments from Bakomi, Rozgrund and Vindšachta water reservoirs were used for analysis after the repaired reservoirs were emptied. Sediment samples were collected so as to be representative, homogenous, and unaltered (uncontaminated) and were collected and transported according to STN ISO 5667-12. Sample collection was conducted using a Jenkins sampler listed in the STN. The water reservoir sediment samples were divided into 6 cm sections at a depth of 42 cm (see Fig. 1).

The sediments were dried at a laboratory temperature of 20°C then ground and meshed to a particle size lower than 1.5 mm. Further, the samples

were homogenised and the analytical sample (100 g) and a duplicate (250 g) were collected. The analytical sample was further adjusted to a 0.125 mm grain size and the sample was consequently used for decomposition (Fig. 2). Sediment samples were mineralised by means of aqua regia according to norm ISO 11466. Each sample was mineralised twice.

After mineralisation, the samples were analysed using the flame atomic absorption spectrometer GBC 933 AA. During measurement, samples were drawn into the flame at a speed of approximately 1 ml per 8-9 seconds and the combustion air to acetylene ratio was set so as to achieve the highest absorptions. For the preparation of calibration curves, single element standards for AAS were used in the form of a water solution concentrated to Mn $1.000 \pm 0.0002 \text{ g.l}^{-1}$ (Merc KgaA, Germany); in 2 % HNO₃ concentrated to Cu, Cd, Pb $1.000 \pm 0.0002 \text{ g.l}^{-1}$ (Analytica Co. Ltd., Praha, Czech Republic); in 0.5 M HNO₃ concentrated to Fe $1.000 \pm 0.0002 \text{ g.l}^{-1}$ (Merc KgaA, Germany).

The measurement of sediment solutions with AAS was repeated three times.

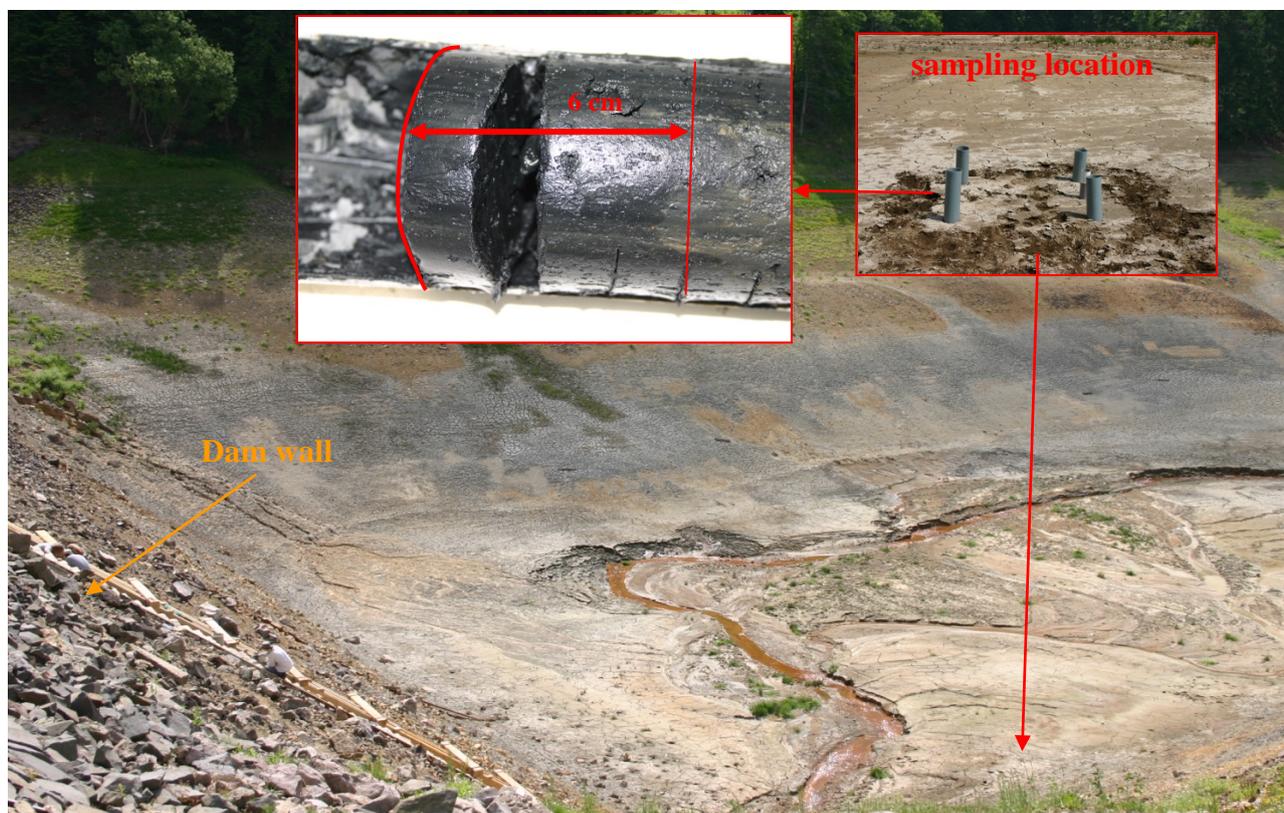


Figure 1. Sampling location Rozgrund

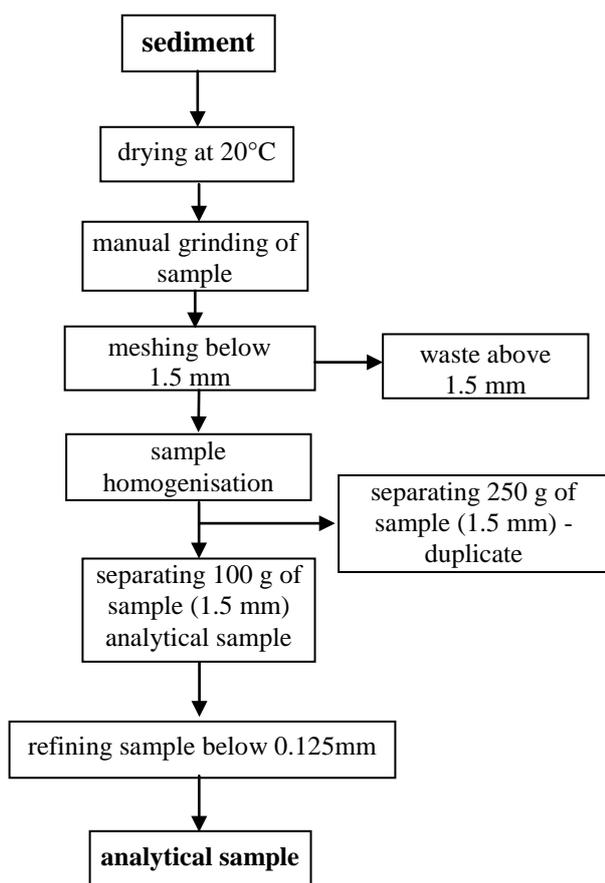


Figure 2. Sample preparation scheme

River Sediment NSC DC 78301, (China National Accreditation of Registrars, Beijing China) and River Clay sediment LGC 6139, (Laboratory of the Government Chemist, Queens Road, Teddington, Middlessex) were used as reference sediment samples and, just as the sediment samples, were subjected to decomposition and measurement.

Uncertainty levels were determined within the evaluation of collected data (Table 1).

5. RESULTS

The concentrations of Cd, Cu, Fe, Mn and Pb metals in water reservoir (Bakomi, Rozgrund and Vindšachta) sample sediments determined through AAS and adjusted to dry sediment sample are listed in table 3.

The average concentrations of Cd in sediments were: Bakomi 2 mg.kg⁻¹, Rozgrund 6 mg.kg⁻¹, and Vindšachta 2 mg.kg⁻¹. The highest concentration of Cd was measured at the Rozgrund location at 18-24 cm depth, 8 mg.kg⁻¹. The Cd concentration at Rozgrund is three times higher than in the Vindšachta and Bakomi reservoir samples.

The average concentrations of Cu in sediments were: Bakomi 17 mg.kg⁻¹, Rozgrund 39

mg.kg⁻¹ and Vindšachta 30 mg.kg⁻¹. The highest concentration of Cu was measured at the Rozgrund location at 18-24 cm depth, 43 mg.kg⁻¹.

The lead concentrations in individual location sediments averaged as follows: 94 mg.kg⁻¹ at Bakomi, 205 mg.kg⁻¹ at Rozgrund, and 96 mg.kg⁻¹ at Vindšachta. The highest Pb concentration was measured at the Rozgrund location at 18-24 cm depth, 231 mg.kg⁻¹. Clearly, the concentration of Pb at Rozgrund is two times higher than at the Vindšachta and Bakomi locations.

The samples we analysed contained the following average concentrations of manganese: 530 mg.kg⁻¹ at the Bakomi location, 1,471 mg.kg⁻¹ at Rozgrund, and 980 mg.kg⁻¹ at Vindšachta. The highest Mn concentration was measured at the Rozgrund location at 36-42 cm depth, 2,031 mg.kg⁻¹. The Rozgrund location is peculiar in that the concentration of Mn increases with depth, where at 0-6 cm it is 563 mg.kg⁻¹ and at 36-42 cm it is 2,031 mg.kg⁻¹. The concentrations of Cd, Cu, Fe, and Pb did not vary much with depth.

In the case of iron, the following average concentrations were measured at the individual locations: 27,601 mg.kg⁻¹ Bakomi, 37,786 mg.kg⁻¹ Rozgrund, 26,884 mg.kg⁻¹ Vindšachta. The highest iron content of 38,623 mg.kg⁻¹ was observed in the Rozgrund location sample from 36-42 cm depth.

6. DISCUSSION

Table 1 and figure 1 show the comparison of measured individual metal levels with the maximum hazardous substance concentration values in bottom sediments listed in the ME SR Act no. 188/2003 Coll. and the Target Value (TV) levels and Maximum Permissible Concentration (MPC) levels in the ME SR methodical guideline no. 549/98-2, the MA SR Decree no. 508/2004 Coll., and the Canadian Environmental Quality Guidelines. The data show that in the case of cadmium, the target value (TV) concentrations, as per the ME SR methodical guideline no. 549/98-2, were exceeded in all locations and samples. According to the MA SR Decree no. 508/2004 Coll. the maximum hazardous substance values for cadmium in agricultural soils were exceeded for all soil types (A, B, and C) in all cases. As per the Canadian Environmental Quality Guidelines, cadmium threshold effect levels (TEL) were exceeded in all cases. A number of research papers deal with the examination of risk factors in the vicinity of Banská Štiavnica, while the attention is focused on the alluvium of Štiavnický brook, which drains water from the problem area (Forgáč et al., 1995; Forgáč et al., 1999; Forgáč et al., 2000; Bajčan et al., 2004).

Table 3. Concentrations of individual, potentially toxic elements in sediments

		Cd	Cu	Fe	Mn	Pb
	Depth	[mg.kg ⁻¹]				
B A K O M I	0-6	3	20	28,832	487	95
	6-12	3	20	30,033	509	98
	12-18	2	18	28,135	529	89
	18-24	3	17	27,321	533	95
	24-30	2	17	26,938	541	104
	30-36	2	16	26,126	547	93
	36-42	2	14	25,824	562	84
	Ø	2	17	27,601	530	94
R O Z G R U N D	0-6	6	42	38,237	563	223
	6-12	5	37	37,423	947	207
	12-18	6	41	37,158	1,443	199
	18-24	8	43	36,624	1,628	231
	24-30	5	38	38,515	1,732	204
	30-36	7	37	37,921	1,955	198
	36-42	5	35	38,623	2,031	171
	Ø	6	39	37,786	1,471	205
V I N D Š A C H T A	0-6	2	29	24,812	889	90
	6-12	2	32	26,573	923	113
	12-18	2	28	27,324	959	101
	18-24	3	33	29,628	994	97
	24-30	2	29	26,988	1092	94
	30-36	3	35	26,235	1235	89
	36-42	2	27	26,631	770	90
	Ø	2	30	26,884	980	96
Uncertainty		30%	25%	10%	20%	15%
549/98-2 TV ¹		0.8	36	-	-	85
549/98-2 MPC ¹		12	73	-	-	530
549/98-2 IV ¹		12	190	-	-	530
508/2004 A ²		0.4	30	-	-	25
508/2004 B ²		0.7	60	-	-	70
508/2004 C ²		1	70	-	-	115
188/2003 ³		10	1000	-	-	750
CN TEL ⁴		0.6	35.7	-	-	35
CN PEL ⁴		3.5	197	-	-	197

¹The ME SR Methodical Guideline no. 549/98-2 for the risk assessment from polluted stream and water reservoir sediments (TV - Target Value, MPC - Maximum Permissible Concentration, IV - Interventional Value)

² MA SR Decree no. 508/2004 Coll. the maximum risk element values in agricultural soil for the following soil types: A – sandy, loamy-sandy soil, B – sandy-loamy, loam, C – clay-loam, clay.

³NC SR Act no. 188/2003 Coll. On the application of sewage sludge and bottom sediments into soil as amended (Maximum concentration limits of risk elements in bottom sediments)

⁴Canadian Sediment Quality Guidelines for Protection of Aquatic Life (TEL - threshold effect level, PEL – Probable effect levels)

The bottom sediment analysis of the brook indicates contamination with Zn, Cd, and also Cu, Pb, and As. The highest Cd concentration detected in the Štiavnický brook sediments was 24.43 g.kg⁻¹. Similarly, the soil is contaminated with Cd, Cu, Pb, Zn, and As. The highest Cd concentration in the soil surrounding the stream was 13.3 g.kg⁻¹, however at a distance of 25 km from Banská Štiavnica. By

contrast, our locations are located at higher altitudes with clearly elevated concentrations of risk elements. The elevated concentrations of some elements stem from both anthropic as well as geogenic contamination. The concentrations of copper at the Rozgrund location were exceeded as per the ME SR methodical guideline no. 549/98-2 for TV, the MA SR Decree no. 508/2004 Coll. for all soil

types (A, B, and C), and the Canadian Environmental Quality Guidelines for (TEL), with the exception of sediment samples taken at 36-42 cm depth.

The copper values were not exceeded at the Bakomi location. In the case of Vindšachta, the values for soil type (A) were exceeded at depths of 6-12, 18-24, 30-36 cm. In the Štiavnický brook sediments, the highest Cu concentration was twenty times higher than the concentration in the samples we investigated. In the Štiavnický brook sediments, the highest Cu concentration was twenty times higher than the concentration in the samples we investigated.

As per the ME SR methodical guideline no. 549/98-2 for TV and the MA SR Decree no. 508/2004 Coll. for soil types (A, B, and C) the lead values were exceeded across the whole profile at the Rozgrund location. At the Bakomi and Vindšachta locations, the maximum risk element values were exceeded, as per the MA SR Decree no. 508/2004 Coll. for soil types (A, B).

The lead levels were exceeded, as per the Canadian Environmental Quality Guidelines for (TEL), in all samples and for (PEL) the values were exceeded at the Rozgrund location in all cases with the exception of sediment samples taken at 36-42 cm depth. In the Štiavnický brook sediments, Pb concentration was approximately ten times higher than the concentration in the samples we investigated.

The results show that the threshold concentration, as per ME SR Act no. 188/2003 Coll., was not exceeded for any one of the Cu, Cd, Pb, Mn, and Fe elements in any of the locations.

As to the dependence of concentration in the investigated metals on sediment depth as well as the composition, the Rozgrund sediment significantly differed from sediments of other lakes. This is probably due to the age of the sediment, estimated at 270 years, since the sediment has not been removed at all in that duration. The Cd concentration at the Rozgrund location is three times higher than the concentration in the Vindšachta and Bakomi water reservoir samples.

The highest Cu (42 mg.kg^{-1}) and Pb (231 mg.kg^{-1}) concentrations were measured at the Rozgrund location at 18-24 cm depth, while the highest Mn ($20,131 \text{ mg.kg}^{-1}$) concentration was detected at 36-42 cm depth.

The Rozgrund location is peculiar in that the concentration of Mn increases with depth. The Mn concentration at 36-42 cm depth is almost four times higher than at 0-6 cm depth. By contrast, in the case of Pb, and partly also Cu, a considerable decrease in concentration was detected (Hroncová &

Ladomerský, 2007).

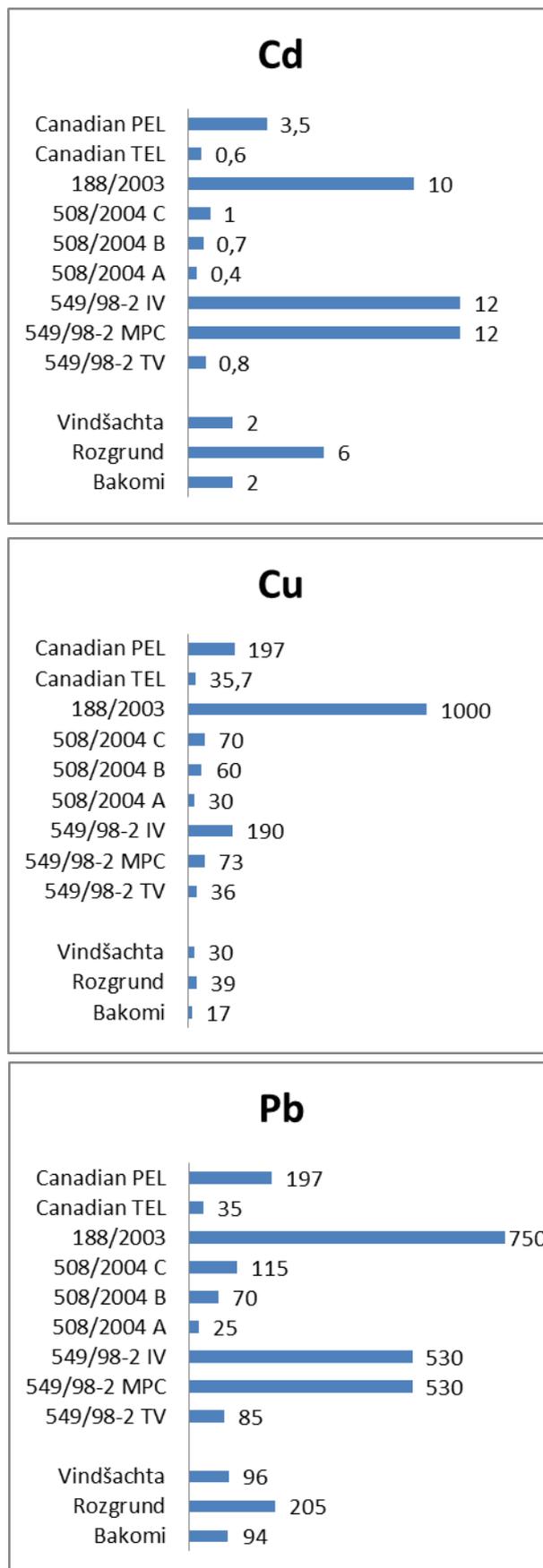


Figure 3. Comparison of average element concentrations [mg.kg^{-1}] with applicable norms

The exceeding of threshold concentration and a maximum permissible concentration for Cu and Cd was noted by a number of authors in several water reservoirs in Slovakia. Brehuv et al., (2003) investigated the individual element contents in the sediments of the Ružín I water works and its tributaries by means of AAS. They found that in the main water works tributary branches of Hornád and Hnilec, adverse values of Cu occurred. Also, the Mn values in the main branch of Hornád were unsatisfactory. The authors concluded that this was due to the fact that those elements bond primarily with silt (0.063 – 0.004 mm) and clay (< 0.004 mm), that is, pelite fraction, or with bottom sediments.

The results of analysis for sediment samples from Zemplínska Šírava Hucko (2005), for individual years did not show significant differences in values. Hg, Be, Mo, Sb, and Se occurred in concentrations up to 1 mg.kg⁻¹. Cd and Sn occurred up to 2 mg.kg⁻¹. The concentrations of Pb, Cu, Cr, and Ni ranged from 20 to 50 mg.kg⁻¹.

In the Starina water reservoir, Hucko (2003), the Cd content exceeded target values in all locations but did not exceed the maximum permissible concentration as per the methodical guideline and Cu concentration was exceeded in two sampling locations. High values of Mn (664-2,589 mg.kg⁻¹) and Fe (30,580-36,910 mg.kg⁻¹) corresponded with the geological underlayer of the Starina water reservoir.

7. CONCLUSION

This paper focuses on the concentration profile determination of potentially toxic elements Cd, Cu, Fe, Mn, and Pb in bottom sediment samples taken from water reservoirs Bakomi, Rozgrund and Vindšachta in the Banská Štiavnica area, a part of UNESCO's World Heritage. The reservoirs were built 250 to 300 years ago while the Rozgrund reservoir was completely emptied, 270 years after its construction. The area is affected by anthropic contamination (approximately 1,000 years of extraction and processing of Au-Ag and Pb-Zn-Cu ores) as well as by geogenic contamination. Individual element volumes in bottom sediments were determined by atomic absorption spectrometry (AAS).

The Bakomi reservoir sediments contained on average in (mg.kg⁻¹): Cd 2, Cu 17, Mn 530, Pb 94, and Fe 27,601. Sediments collected at the Vindšachta location contained on average in (mg.kg⁻¹): Cd 2, Cu 30, Mn 980, Pb 96, and Fe 26,884.

The Rozgrund sediment differed more significantly from sediments of other lakes. The

Rozgrund location sediments contained on average in (mg.kg⁻¹): Cd 6, Cu 39, Mn 1,471, Pb 205, and 37,786 Fe. The concentration of Mn increased almost evenly with increased depth.

The results show that, as per the ME SR no. 188/2003 Coll., the threshold concentrations for any one the cases (Cu, Cd, Mn, and Fe) were not exceeded at any of the locations.

In terms of the ME SR guideline no. 549/98-2, the MA SR Decree no. 508/2004 Coll. and the Canadian Environmental Quality Guidelines, the TV, TEL, and PEL values for sediments and the maximum risk element values in agricultural soils were exceeded in some cases. The investigated elements did not show concentrations as high as those in the alluvium of Štiavnický brook, which drains water from the Štiavnické Mountains.

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