Acta Sci. Pol.
Formatio Circumiectus 25 (2) 2026, 111–123
ENVIRONMENTAL PROCESSES

www.acta.urk.edu.pl ISSN 1644-0765 DOI: http://doi.org/10.15576/ASP.FC/221920

ORIGINAL PAPER Accepted: 15.05.2026

THE IMPACT OF TRIBUTARY BOTTOM MATERIAL ON BOTTOM SEDIMENTS IN THE KUČIŠDORF AND HARMÓNIA RESERVOIRS

Andrej Válek[1,2]✉, Lubos Jurik[1] 0000-0003-4533-5915,
Aybek M. Arifjanov[3] 0000-0003-2599-4892, Peter Halaj[1] 0000-0002-7464-9625,
Marta Lenartowicz[1] 0009-0005-1245-9833, Tatiana Kaletova[1] 0000-0003-2695-1448

[1] Institute of Landscape Engineering, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture in Nitra, Slovakia
[2] Slovak Water Management Enterprise, Bratislava, Slovakia
[3] Department of Hydraulics and Hydroinformatics, Faculty of Hydromelioration, National Research University "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers", Uzbekistan

ABSTRACT

Aim of the study

The objective of the present study was to analyse the presence of metal elements in bottom sediments of water reservoirs in the basins of streams flowing from mountain ranges, containing metals, and to compare them with the composition of the tributary bottom material representing part of the parent rock of the basin, specifically Fe, Zn, As, Sr, Zr, Al and Ni. The subsequent step involves determining the transport of these elements within the streams and their subsequent accumulation within the reservoir.

Material and methods

The study was conducted in two water reservoirs: Kučišdorf in the Pezinok cadastral area, and Harmónia in the Modra cadastral area. Both water works serve mainly for the recreation and sport fishing. The samples were taken in 2024, and analysed in 2024 and 2025. Samples were analysed using a handheld X-ray fluorescence spectrometer (XRF), model Vanta. The arithmetic mean was calculated from the five performed analyses, which were then used in the evaluation. The results were processed in MS Excel.

Results and conclusions

The results indicate that the bottom material at the inflow and reservoir bottom sediments contain a wide variety of elements, including a wide range of metals. It is evident from the results that the concentrations of the monitored elements are principally supplied to the bottom sediments from the tributary bottom material, and that these elements are accumulated in the sediments.

Key words: tributary bottom material, water reservoir, bottom sediments, metals, catchment

INTRODUCTION

The majority of water reservoirs (WRs) in Slovakia were constructed in the twentieth century. The principal functions of water resources include the provision of water for supply, the irrigation of agricultural crops, and the protection of floodplains (Jurík et al., 2011). The construction and operation of dams can also exert a considerable negative influence on hydrological regimes. It is evident that the construction of a dam

✉e-mail: andrej.valek.svp@gmail.com

can result in fundamental alterations to the hydrology of the basin. Consequently, the operation of the dam carries the potential to introduce dynamic variations in streamflow. Furthermore, the presence of dams has a significant impact on the transportation of sediments within the basin (Mailhot et al., 2018; Valdelamar-Villegas et al., 2021).

Bottom sediments represent an integral functional component of aquatic ecosystems. Sediments are frequently designated as geosorbents of pollutants in the aquatic environment, due to their capacity to adsorb and absorb pollutants. Sediments are known to contain organic and inorganic substances of natural and anthropogenic origin, thus rendering them a significant source of information for the purposes of aquatic environmental monitoring and pollution assessment (Tomczyk-Wydrych and Świercz, 2021). It is widely acknowledged that lakes and reservoirs function as long-term repositories for both externally-derived allochthonous sediments resulting from water and wind erosion, and autochthonous sediments produced in situ by biological activity (e.g., bank abrasion and eutrophication) (e.g., Wetzel, 2001; Wynants et al., 2020). Soil erosion is an inevitable process that is accelerated by human activity, especially agriculture. Furthermore, deforestation of large areas has been shown to accelerate erosion processes in the landscape (Muchová and Konc, 2010). Bank abrasion is defined as the damage to the bottoms and banks of a watercourse or a WR caused by water currents or waves associated with the movement and deposition of loose material (Šlezingr, 2011). The process of internal siltation is characterised by the accumulation of particulate matter within reservoirs, resulting from the decomposition of dead plant and animal biomass within the water body. Eutrophication, a process characterised by an excess of nutrients, is precipitated in reservoirs by a combination of erosion processes and municipal pollution (Malmaeus and Håkanson, 2004). The consequence of this is the rapid proliferation of microscopic and macroscopic flora in the water (Bhagowati et al., 2019). After the organisms' death, the substance settles in the form of fine organic material, otherwise referred to as sapropel (Jurík et al., 2011).

The bottom sediments of small WRs are the result of the joint action of natural processes and human activities in the water basin of the WRs. The natural processes which occur in this region are the result of three main factors: Firstly, the constant disintegration of rocks of the geological composition of the parent rocks of the basin; secondly, the slow transport of these rocks in watercourses within the area; thirdly, the erosion of soils in the basin. Anthropogenic influences are characterised by the contribution of substances and elements from the economic activities of people or households in the basin (Gavrilas et al., 2025). The binding processes of trace elements are known to vary considerably depending on the sediment composition, structure and properties. The literature suggests that climate, parent rocks and sediment properties − such as acid-volatile sulphides, organic matter, texture, pH, redox potential, as well as organism behaviour − influence trace element content in bottom sediments (Zhang et al., 2014; Wang et al., 2014; Baran et al., 2019; Birch et al., 2021). In bottom sediments, trace elements are found to be bound within the structure of minerals, present as chemical compounds (sulphides, carbonates, oxides), or in forms absorbed by clay minerals, organic matter, or hydrated iron hydroxides (Wang et al., 2014; Gao et al., 2021). As demonstrated in the field studies conducted by Zainescu et al. (2023) and Luo et al. (2022), the velocity of wind, the depth of the water, and the properties of the sediment have been shown to have a considerable effect on the process of sediment transport and the turbidity of the water column. However, field-based methods are fundamentally constrained by their lack of control over environmental factors, which complicates the task of isolating particular mechanisms and processes (Addona et al., 2018).

Sediments are distinguished by their elevated mineral content, a property that is indispensable for promoting plant growth and replenishing the soil's mineral reserves. It has been established that the function of this mechanism is to facilitate the movement of nutrients, such as nitrogen and phosphorus, which are adsorbed, from one area to another. Sediments frequently contain organic matter, a component that is imperative for soil health due to its ability to enhance nutrient retention and provide sustenance for soil microbes (Kaletova et al., 2022). In contrast, the contamination of sediments with trace elements has become a growing global problem in recent years. This is especially concerning given that it poses a threat to living organisms in the aquatic environment (Shirani et al., 2020). It has been determined that more than 90% of the metal pool in water reservoirs is present in sediments (Zhang et al., 2014). In the event of bottom sediments exhibiting a suitable chemical composition, they can be utilised for a variety of purposes, including soil enrichment, land reclamation, waste landfill, and composting. In order to circumvent the potential adverse repercussions on the landscape, water resources and human health, the limits for selected elements in the sediments have been established in several countries. The principles governing the use of sediments in the Slovak Republic are also subject to legal regulation (Macura and Halaj, 2013).

It is hypothesised that the concentrations of elements in the bottom sediments of selected reservoirs are exclusively the result of natural processes and can therefore be utilised in land reclamation. The objective of this study is to elucidate the spatial redistribution of substances within the sediments at the base of the reservoir, a consequence of numerous processes. A detailed analysis of sediments at multiple locations within the reservoir is intended to enable the creation of an analogy for other reservoirs, as this approach is time-consuming as well as technically and financially demanding. The main objective of this study is to analyse the concentrations of selected elements (Fe, Zn, As, Sr, Zr, Al, and Ni) that typically occur in the host rock environment represented by the bed material of tributaries. These elements are of particular interest as a result of environmental effects on the host rock at the source in the bottom sediments of the studied reservoirs. Elevated concentrations of the aforementioned elements have the potential to exert a detrimental effect when employed in the context of land reclamation.

MATERIALS AND METHODS

In order to achieve the objectives of the study, the parent rock was examined in the form of the larger bottom materials of tributaries to the reservoirs. The said materials were formed by the disintegration of rocks in the area. The elements in question are present in the natural composition of rocks within the basin, but they can also be found in waters flowing into the stream from the basin area (Polák et al., 2012). An evaluation was conducted to ascertain the fluctuations in elemental concentrations, the variations in concentrations between discrete sediment sampling points within the WRs, and the percentage increase or decrease in the concentrations of dissolved elements relative to the material present in the inflow to the reservoir.

Study area

The selection of the WRs was based on the elevated levels of metals present in the parent rocks of the respective basins based on the geological maps. In the basin area of the selected reservoirs, the geological structure is formed by biotic granodiorthysts, quartzites and siliceous phyllites with biota. These rocks are of both igneous and sedimentary origin, and they contain gold, silver, antimony, lead, zinc, and, most notably, iron. It is significant that some metal deposits in the Malé Karpaty Mountains, where the proposed site is located, have also been utilised economically. As demonstrated by the hydrogeological map of the Slovak Republic, it can be concluded that the immediate vicinity of the Kamenný potok and Trniansky potok, which are the primary tributaries of the selected WRs, possess a lithographic structure of fluvial sediments, comprising sands and sandy clays.

The impact of the transportation of elements from the parent rock, throught the tributary bottom material as a result of the erosion processes in the landscape, to the streams and reservoirs in the area under study on the composition of bottom sediments was the focus of an evaluation at the Kučišdorf WR and Harmónia WR. The Kučišdorf WR is located in the cadastral area of Pezinok, while the Harmónia WR is located in the cadastral area of Modra, on the foothill of Malé Karpaty in the Pezinok district of the Bratislava region (Fig. 1). The transportation of elements and sediments is contingent on numerous factors and processes. Sediments are most often transported by the force of gravity from higher to lower regions. This phenomenon is further compounded by the movement of substances from the banks to the centre of the reservoir or to the lowest point in the valley. The movement is initiated by means of a glide along the posterior aspect of the body, or, in circumstances of elevated water flow, it can be linked to movements of buoyant nature.

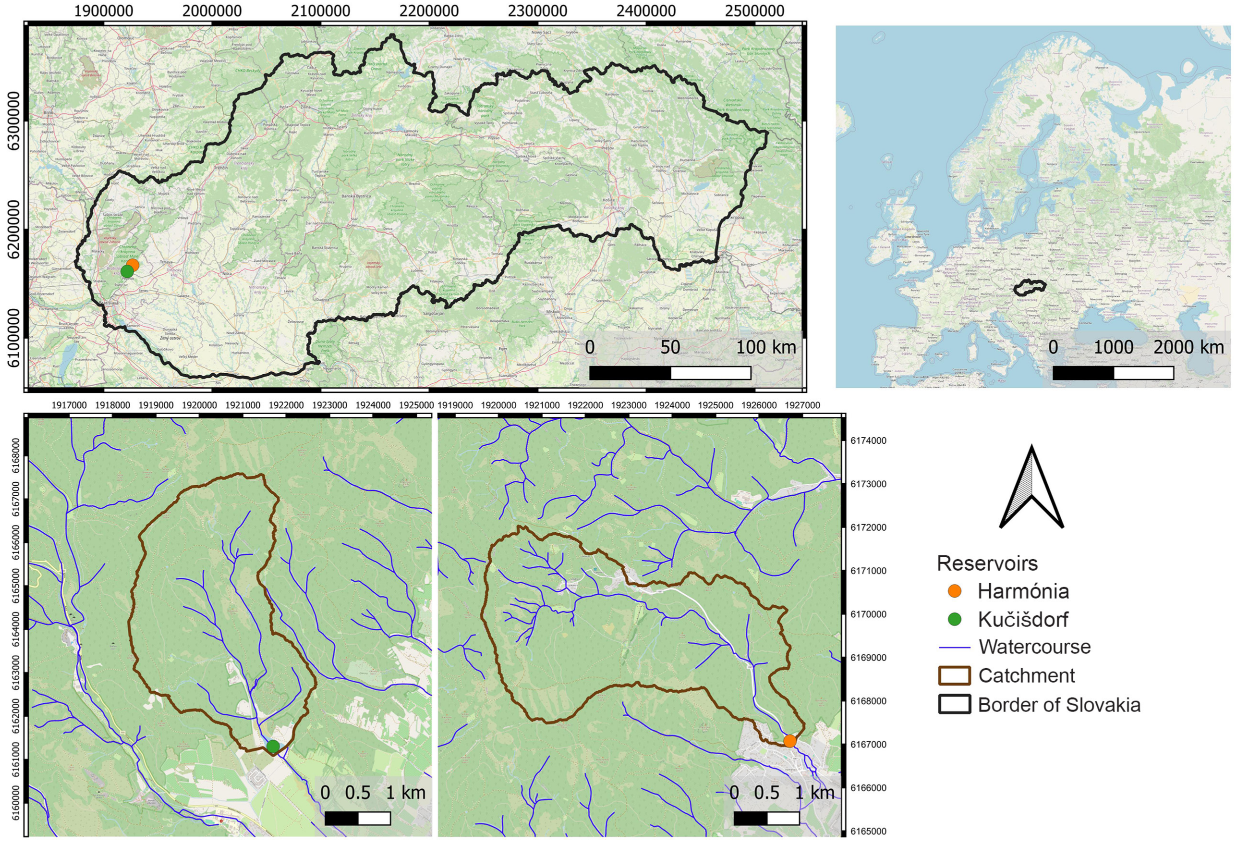

Fig. 1. Location of selected water reservoirs (Source: © OpenStreetMap, modified by the authors)

Fish are present in all reservoirs and their diet consists primarily of organisms known as macrozoobenthos. In pursuit of these organisms, fish cause a disruption to the sediment layer, resulting in its resuspension and subsequent dispersion in various directions.

A separate source of sediments is constituted by the remains of dead organisms in the water column, primarily planktonic in nature, with algae and cyanobacteria being particularly notable examples. These objects are observed to descend directly to the bottom of the water surface, irrespective of geographical location. During the process of sedimentation, organic matter and inorganic substances are mixed.

The Kučišdorf WR is classified as a valley reservoir, characterised by its flow-through design. It possesses a catchment area of 9.00 km^2, encompassing a flooded area of 7.96 ha. It was constructed between 1982 and 1986, and has been in permanent operation from the 1986 onwards. The slope of the catchment varies from 0 to 69.23° (Fig. 2). The dam is of an earthen, homogeneous nature, measuring 526.5 m in length and displaying a kink in its plan (Fig. 3a). The structure is built on the Trniansky potok, which exhibits an average slope of 6.83% (Fig. 2). The reservoir is of significant importance in the region, as it functions as a water supply for the Viničiansky kanal, which in turn serves to facilitate the management of the Viničné WR and Blatné WR. It is also used for the extensive fish farming (Brezovský, 2003). The Kučišdorf WR catchment area is predominantly forested and includes a cottage area. The lithology of the Kučišdorf water basin is primarily composed of deluvial sediments, comprising sediments, clays, stony rubble, and Varín plutonites with granodiorites, diorites, granites, aplites, and pegmatites (Polák et al., 2012).

The Harmónia WR is a valley reservoir, flow-through, with a catchment area of 9.34 km^2, a flooded

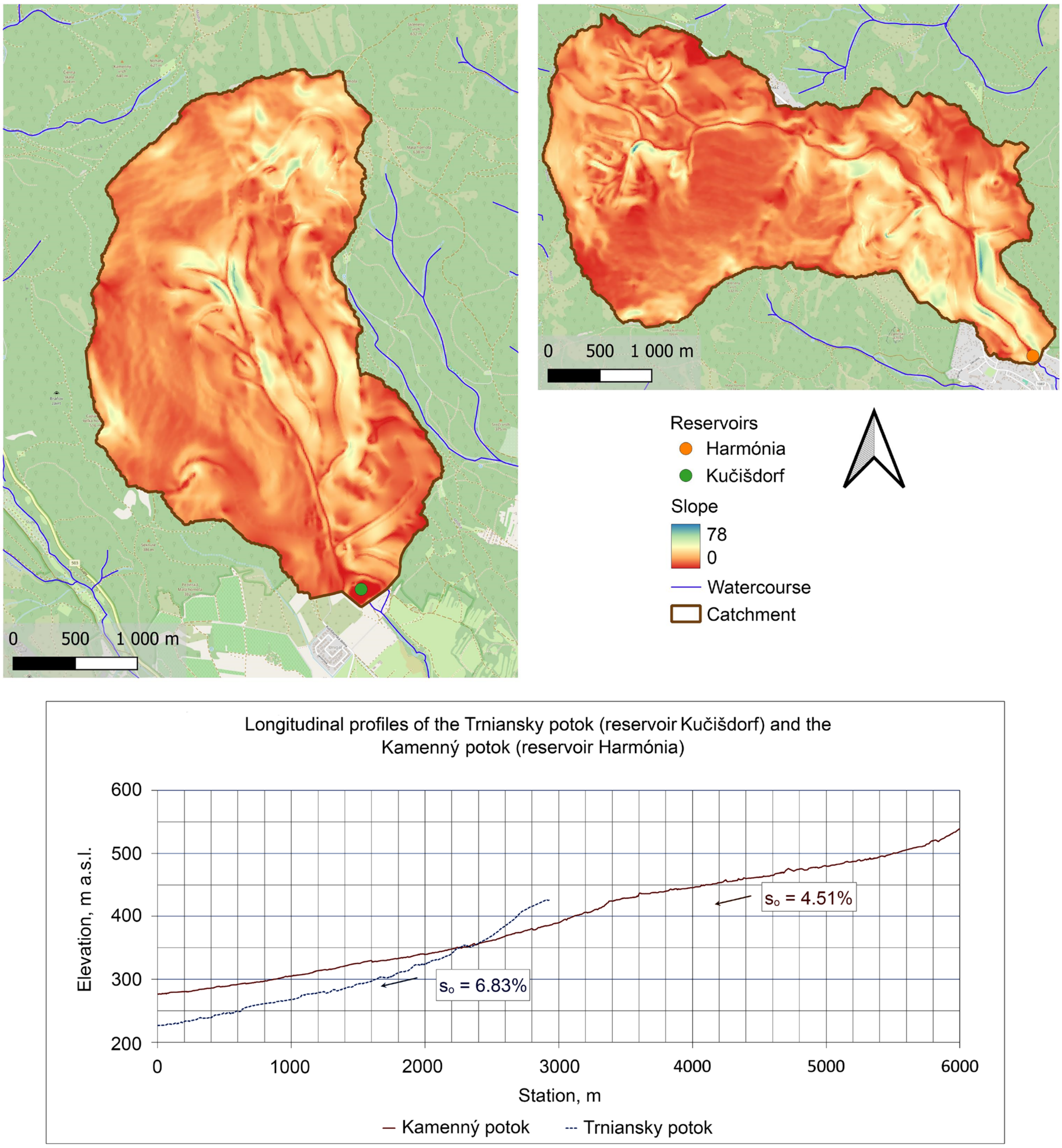

Fig. 2. Slope of the catchments and longitudinal profiles of related watercourses (Source: © OpenStreetMap, modified by the authors)

area of 1.66 ha, and catchment slopes from 0.01 to 78.38° (Fig. 2). The dam is of an earthen, homogeneous nature, with a length of 85 m (Fig. 3b). It was built between 1962 and 1963, and it has been in permanent operation from 1963. The structure is erected on the banks of the Kamenný potok, which exhibits an average slope of 4.51% (Fig. 2). The reservoir is also used for extensive fish farming (Povodie Dunaja, 1993). The catchment area is predominantly composed of forests and rural settlements. The lithology of the Harmónia water basin was determined to comprise phyllites, micaceous schists, metapilites, black schists, Variscan plutonites; granodiorites, diorites, granites, aplites, pegmatites, Ariscan plutonites; granodiorites, diorites, granites, aplites and pegmatites (Polák et al., 2012). A notable similarity exists in the composition of the basins of both WRs, characterised by the prevalence of Aryan plutonites, granodiorites, diorites, granites, aplites and pegmatites.

Sample collection and laboratory analysis

The present study examined the transfer of naturally occurring metals into the sediments of the reservoir, as well as the method of their accumulation or further transport to the lower parts of the basin. Therefore, sampling points were established at the inflow to the reservoir and subsequently in three sections of the water accumulation area within the reservoir itself (Fig. 3). The samples of several gravels of different colours and composition from tributaries were collected manually, using hand tools, prior to the gravel entering the water reservoir at point 1. The samples were then prepared for analysis by washing in demineralized water. The samples of bottom sediments were collected from the reservoirs by boat from three locations: at the mouth of the streams into the water reservoir (point 2), in the middle (point 3), and about 25 metres from the dam (point 4). Due to the fact that the samples were collected beneath the water level, the bottom sediment samples were extracted from the sediment surface layer, which had a thickness of approximately 15 centimetres. The collection of bottom sediments and gravels from the tributaries was conducted in 2024. To increase the reliability of the results, bottom sediments were collected again in 2025, and compared with the previous set.

The samples of bottom sediments were placed in sealed plastic bags and transported to the designated laboratories for further processing. The quantity of sediment samples collected at each site ranged from 2 to 3 kilograms, with approximately 100 grams of the material being allocated for subsequent analysis. The

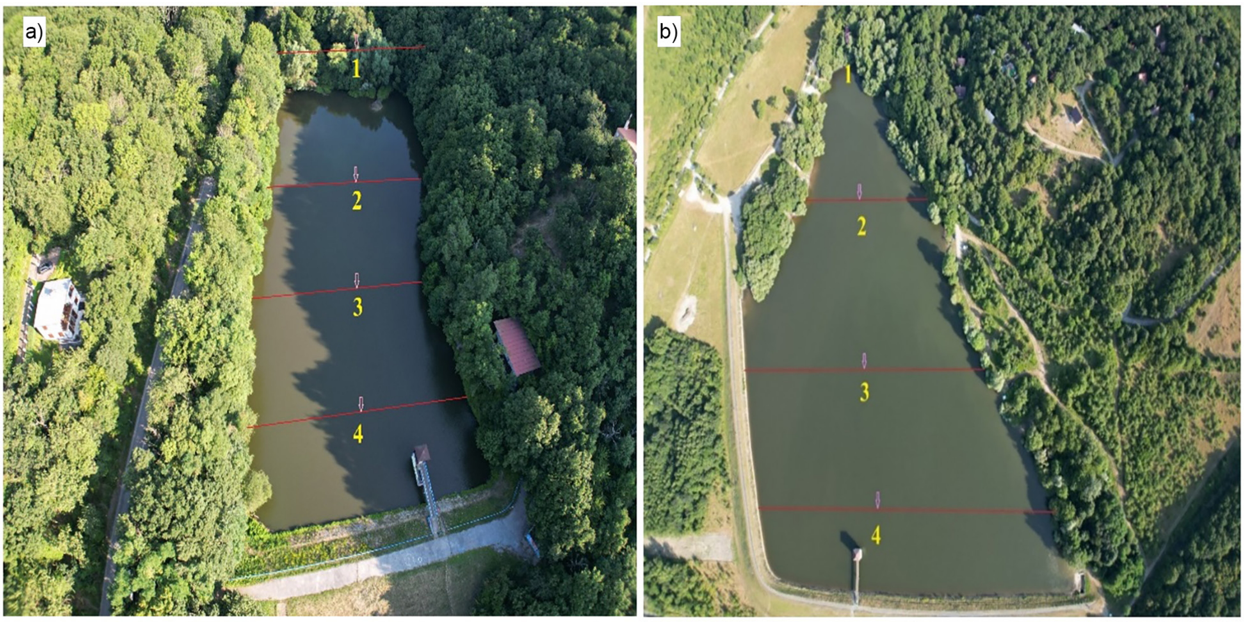

Fig. 3. Sediment sampling points in water reservoirs: a) Harmónia, b) Kučišdorf (Source: Authors' own elabaration)

sample utilised for the analysis was a composite of multiple minute quantities of the entire sample.

Subsequently, the bottom sediment samples were prepared for analysis by:
1) drying of the samples in a laboratory oven at a temperature of 105°C until constant weight;
2) crushing;
3) sieving with the sieve size set at 2 mm.

Prior to the analysis, a homogenisation process was employed, whereby the samples were thoroughly mixed.

Samples of reservoir sediments and rock formations from the tributary's bottom were analysed using a handheld X-ray fluorescence spectrometer (XRF), model Vanta. In order to enhance the reliability of the results, it was necessary to analyse each sample from each sampling point on five separate occasions. The initial sample of each point was mixed between individual measurements, and the entire content of the sample was exchanged between the third and fourth measurements. The arithmetic mean was calculated from those five analyses at the sampling point, which were then used in the evaluation. A total of 30 analyses of bottom sediments were performed from each reservoir for both years. The results were processed in MS Excel.

RESULTS

The concentrations of individual elements in the material at the bottom of the inflow and in the reservoir itself were found to differ. The individual values for the monitored elements corresponded to the geological composition of the rocks in the basin. The content of the most prevalent metals in nature, aluminium (Al) and iron (Fe), was found to be the highest at all points, while the concentrations of arsenic (As) and nickel (Ni) were found to be the lowest (see Table 1 for details). The same results were obtain for both sets of samples from 2024 and 2025. The difference in the mean values was up to 1% (10 000 mg · kg^{-1}) in case of Fe and Al, and up to 5 mg · kg^{-1} in case of the other elements.

A comparison of the results pertaining to the concentrations of selected elements in bottom sediments with the limit values specified in Act No. 188/2003 Coll. is warranted (As 20 mg · kg^{-1}, Ni 300 mg · kg^{-1}, Zn 2500 mg · kg^{-1}). It is evident that the application of sewage sludge and bottom sediments to soil, in accordance with Standard STN 46 5735 industrial composts, results in element concentrations in bottom sediments falling below the maximum permitted values stipulated in the aforementioned legislation. In order to assess the possibility of applying bottom sediments to agricultural land, or possibly using them for industrial composting, it would be necessary to evaluate the remaining parameters specified in these regulations − and that is not the subject of this study.

The elevated concentrations of elements in the reservoir relative to those in the tributary indicate their accumulation in the sediments. This phenomenon is deleterious to the biota inhabiting the reservoir. In the tributary bottom material from Trniansky potok (point 1), in the Kučišdorf WR the concentrations of the elements under scrutiny are listed in descending order as follows: Al > Fe > Sr > Zr > Zn > Ni > As, in points 2 and 3 of the reservoir: Al > Fe > Zr > Sr > Zn > Ni > As, and in point 4: Al > Fe > Sr > Zn > Zr > Ni > As (see Table 1). Within the context of the descending rankings, the elements Al, Fe, Ni and As have demonstrated a consistent and predictable position. In points 1 and 4, the elements occupying the central position in the chain, namely Zr, Sr and Ni, undergo a change in their relative ranking. The concentration of all the analysed elements in the bottom sediments is greater in point 4 (close to the dam) than in the bottom material of the tributary.

In the Harmónia WR, the concentrations of five elements that were monitored – aluminium (Al), iron (Fe), zinc (Zn), nickel (Ni), and arsenic (As) – have been shown to be at a stable point of order. The descending order of elements in the analysed points 2, 3, and 4 is: Al > Fe > Zr > Sr > Zn > Ni > As. In the tributary bottom material of the Kamenný potok, an exchange of positions between the elements Sr and Zr was observed. In the Harmónia WR, the concentration of all elements except Sr is greater at point 4 than in the tributary bottom material (Table 1). The same results were obtained in the 2025 (Table 2). The concentration of elements were mostly higher; nevertheless, the differences are negligible.

It is noteworthy that the mean value of the concentration of the element As is equivalent in both reservoirs at all sampling points.

Table 1. Average values of concentrations of monitored elements in mg · kg^{-1} dry sediment in 2024

Locality / Element		Fe	Zn	As	Sr	Zr	Al	Ni
Trniansky potok	1	10 916	64	3	81	76	13 379	7
WR Kučišdorf	2	19 359	80	8	265	312	54 837	14
	3	30 346	129	10	229	240	66 794	27
	4	31 930	124	12	222	123	65 740	25
Kamenný potok	1	14 706	59	3	243	114	56 751	6
WR Harmónia	2	23 048	141	8	193	207	46 667	21
	3	26 900	164	10	186	224	58 122	27
	4	29 519	178	12	185	188	59 366	31

Table 2. Average values of concentrations of monitored elements in mg · kg^{-1} dry bottom sediments in 2025

Locality / Element		Fe	Zn	As	Sr	Zr	Al	Ni
WR Kučišdorf	2	23 384	111	10	252	296	56 955	21
	3	29 573	131	10	244	267	68 847	27
	4	33 064	140	13	228	188	70 088	28
WR Harmónia	2	24 616	152	8	201	248	55 622	25
	3	27 683	173	9	196	235	62 880	30
	4	30 825	187	11	191	186	69 629	33

In the Kučišdorf WR, the concentrations of the elements Zn, Al and Ni exhibit an increasing trend from point 1 to point 3, and a decrease towards the dam (see Table 3). The concentrations of the elements Sr and Zr exhibit an increasing trend from point 1 to point 2, followed by a decrease. In the Harmónia WR, an increasing trend is evident in the concentrations of the elements Fe, Zn, As and Ni across all points. The concentration of the element Sr exhibits a decreasing trend across all points. The concentration of the element Zr exhibits an increasing trend between points 1 and 3, and a decreasing trend between points 3 and 4. The concentration of aluminium (Al) exhibits a decrease between points 1 and 2, followed by an increase from point 2 to point 4.

In both reservoirs, the concentrations of the elements Fe and As exhibited analogous trends, with an increase observed across all points.

Table 3. The course of the rise and fall of concentrations between individual points in mg · kg^{-1}

Locality / Element		Fe	Zn	As	Sr	Zr	Al	Ni
Trniansky potok	1	10 916	64	3	81	76	13 379	7
WR Kučišdorf	2	↑*	↑	↑	↑	↑	↑	↑
	3	↑	↑	↑	↓*	↓	↑	↑
	4	↑	↓	↑	↓	↓	↓	↓
Kamenný potok	1	14 706	59	3	243	114	56 751	6
WR Harmónia	2	↑	↑	↑	↓	↑	↓	↑
	3	↑	↑	↑	↓	↑	↑	↑
	4	↑	↑	↑	↓	↓	↑	↑

* red arrow shows the course of the increase; green arrow shows the course of the decrease of the element content

The values obtained demonstrate that in the Kučišdorf WR, the most significant percentage increase is observed for Al at point 3, reaching almost 500% (Table 4), while the least significant percentage increase is recorded for Zn at point 2, with an increase of 125%. It is evident that there had been a substantial increase in the concentration of all elements, with the elements accumulating in the reservoir sediments. The highest concentrations are observed in the central region of the reservoir. A minor decline in the outflow can be attributed to the partial displacement of sediments, resulting in the water flowing out of the reservoir through the outlet mechanism.

In the Harmónia WR, a decrease in the percentage of the element Sr was observed at all points relative to the source, and a decrease in the percentage of the element Al was recorded at point 1 relative to the source (Table 4). The most significant percentage increase is observed for Ni at point 3, with an increase of almost 521%, while the least significant percentage increase is recorded for Al at point 2, with an increase of 102%. The distribution of concentrations is analogous to that observed in the Kučišdorf Reservoir.

DISCUSSION

In this study, the XRF method was utilised to analyse all elements measurable at each site. Through this analysis, seven elements were identified as being present at both sites. The results unequivocally demonstrate that Fe and Al are present in higher concentrations than the other five elements, primarily in the fine-grained fraction, indicating that they originate from the soils of the watershed. Although measuring the correlation between particle size and concentration of the elements is not the main objective of the article, this claim is supported by other authors (López et al., 2016; Que et al., 2024; Ciu et al., 2025). Heavy metals are primarily found on the surface of sediment particles and are transported via particulate matter as carriers. Consequently, the size of sediment particles has the capacity to influence the adsorption and release and migration of heavy metals (Que et al., 2024). The other elements are present in the gravelly parts of the bottom sediments. The concentration trend increases from the inflow section of the reservoir towards the dam. This finding serves to substantiate the physical principles that govern the natural movement of substances along the reservoir bottom in relation to the bottom's elevation. The reservoirs have not been subject to drainage for a considerable number of years; therefore, this process is not influenced by sediment transport during complete drainage, as is common in our country when reservoir use is combined with intensive fish farming. As demonstrated by López et al. (2016), the mean particle size was found to decrease from tail to dam. The process of desiccation resulted in an increase in particle sorting, with a concomitant shift in the size distribution towards a bimodal pattern. However, no discernible effect on the average size of the particles was observed (López et al., 2016).

In Slovakia, the chemical composition of bottom sediments has been addressed predominantly from the perspective of legislative regulations valid in the Slovak Republic. As stated in the Geochemical Atlas of the Slovak Republic, in Part VI: River Sediments

Table 4. Element concentration ratio relative to the tributary bottom material in percentage [%]

Locality / Element		Fe	Zn	As	Sr	Zr	Al	Ni
Trniansky potok	1	100	100	100	100	100	100	100
WR Kučišdorf	2	177.35	125.00	278.97	327.16	410.53	409.87	200.00
	3	278.00	201.56	347.12	282.71	315.79	499.25	385.71
	4	292.51	193.75	389.16	274.07	161.84	491.37	357.14
Kamenný potok	1	100	100	100	100	100	100	100
WR Harmónia	2	156.72	239.67	278.97	–20.77	181.19	–17.768	349.00
	3	182.92	278.23	347.12	–23.49	196.44	102.42	452.98
	4	200.73	302.32	389.16	–24.07	165.12	104.61	520.55

(Bodiš et al., 2011), the minerals pyrite and pyrrhotite, in addition to the elements Fe, S, Sb, As, Cu, Zn, Ni and Co, have been identified at the studied site. The mean values of the elements under study in river sediments in Slovakia are as follows: The mean concentrations of Fe, Zn, As, Sr, Zr, Al and Ni were determined in the study, with Fe recorded at 2.86 ± 120%, Zn at 116 ± 237 mg · kg^{-1}, As at 11 ± 49 mg · kg^{-1}, Sr at 148 ± 80 mg · kg^{-1}, Zr at 408 ± 190 mg · kg^{-1}, Al at 5.8 ± 1.4% and Ni at 27 ± 35 mg · kg^{-1} (Bodiš et al., 2011). A comparison of the mean values of element concentrations achieved in river sediments in Slovakia with the results of values measured on tributaries to WR reveals that the mean values of element concentrations measured by us in the present study, are lower, in the majority of cases (see Table 1 and 2).

In the context of Slovak conditions, the focus on bottom sediments was predominantly directed towards large WR. For instance, the sedimentation reservoir of WR Ružín on the Hnilec River exhibited concentrations of 59.55 mg · kg^{-1} of As, 52.20 mg · kg^{-1} of Ni, and 631.05 mg · kg^{-1} of Zn, while the sedimentation reservoir of WR Ružín on the Hornád River displayed concentrations of 52.09 mg · kg^{-1} of As, 71.91 mg · kg^{-1} of Ni, and 304.60 mg · kg^{-1} of Zn. The basins of these streams are predominantly impacted by mining and ore processing activities. The Veľké Kozmálovce reservoir exhibited lower concentrations (42.56 mg · kg^{-1} for As, 14.58 mg · kg^{-1} for Ni, and 463.44 mg · kg^{-1} for Zn) when compared to other reservoirs. However, it is important to note that this reservoir has a large basin (4,015.67 km^2) that is affected by anthropogenic impacts from surface runoff, sewage, as well as industrial and municipal wastewater (Šutriepka, 2007). The concentrations of As and Zn elements in all mentioned WRs are found to be several times higher than in the Harmónia and Kučišdorf WR. These WRs have significantly smaller catchments with a predominance of forest and are less affected by anthropogenic activity. Nickel concentrations are comparable.

The findings from Poland and the Czech Republic further substantiate the correlation between the size of the catchment area and its utilisation. Sediments from reservoirs with extensive catchment areas, influenced by anthropogenic activities, exhibit elevated concentrations of elements in comparison to those from reservoirs with limited catchment areas or minimal human impact. The WR Rybnik (Poland), which is characterised by a significantly affected catchment area due to the impact of human activity and heavy industry (with a catchment area of more than 316 km^2), exhibits elevated concentrations of elements (As: 8.2 mg · kg^{-1}; Ni: 26.2 mg · kg^{-1}; Zn: 692 mg · kg^{-1}). This is in comparison to WR Rożnów, which is characterised by a surrounding mountainous environment with an agricultural character (and a catchment area of more than 4800 km^2) and which exhibits elevated concentrations of elements (As: 5.3 mg · kg^{-1}; Ni: 38.3 mg · kg^{-1}; Zn: 75.3 mg · kg^{-1}) (Boguta et al., 2022). Elevated concentrations of elements in bottom sediments can also have a natural origin from the geological subsoil, as evidenced by the moraine Górecki Lake in Poland, where almost the entire basin is forested (Zerbe et al., 1999). However, as Halili and Demaku (2025) report, there is a significant difference in the distribution of heavy metals in streams influenced by human activity and natural geological factors. This assertion is further substantiated by the observation that this phenomenon is not exclusive to WRs but extends to reservoirs of varied uses and their respective environments (Sojka et al., 2019). Fishponds, one of the WR types, located within forest environments, exhibited the lowest medians of As and Zn, while in the case of Ni, the lowest median was observed in ponds situated in agricultural landscapes. Ponds situated in proximity to human settlements have been observed to exhibit the highest concentrations of dissolved elements (Vácha et al., 2011). In these reservoirs, as well as in river sediments and in the WR Kučišdorf and WR Harmónia, the sequence Zn > Ni > As is observed. In larger reservoirs on Slovak watercourses, the prevalence of As over Ni was observed.

The utilisation of comparatively modest amounts of reservoir sediments has been demonstrated to constitute an economically feasible approach for the undertaking of land reclamation projects (Girmay et al., 2012). Sediments are utilised for the purpose of filling eroded patches and enhancing soil productivity. These materials are characterised by their high phosphorus content and the presence of exchangeable cations, which functions as a substitute for fertilisers, particularly when employed in conjunction with manure (Girmay et al., 2012; Gomez et al., 2025). Moreover, dredged materials can be utilised for land improvement purposes, such as the creation of new topsoil, landfill cover, and construction fill material (Qureshi et al., 2021). It is evident from the results that the sediments of Harmónia and Kučišdorf WRs should be utilised primarily for the land reclamation of eroded patches, landfill cover and material for construction. Subsequent analysis will determine the optimal utilisation of these materials.

CONCLUSIONS

It is evident from the analysis of the elements represented in river bottom sediments in Slovakia that the monitored concentrations of elements in the bottom sediments of the Kučišdorf and Harmónia WRs are influenced by the tributary bottom material and the natural forest environment. The concentrations observed in the tributary are indicative of the geological processes of natural rock weathering. It is possible to demonstrate this phenomenon, particularly in the context of the elements As, Zn, Sr, Zr and Ni. The current measured values of parameters in sediments treated by monitored WRs were significantly lower than the values in sediments in large reservoirs, or reservoirs with a larger catchment area. Given the negligible influence of industrial activity on the monitored water reservoirs with small catchments, it is evident that the measured values of the concentrations of the elements Fe and Al are more indicative of forestry and agricultural activity in the catchments of the WRs. Consequently, it can be deduced that the elevated concentration of these elements in sediments relative to the tributary bottom material may be attributable to accumulation. Owing to their elevated geogenic content, it is extremely challenging to ascertain the proportional impact of anthropogenic activity.

The findings of the measurements demonstrated that the surrounding environment of the site exerts an influence on the chemical composition of the sediments. Despite the fact that reservoirs with a rock environment and a significant content of a wide range of metals were deliberately selected for the solution, their concentrations in the reservoir did not exceed the limit values set for the use of sediments on agricultural or forest land. The absence of anthropogenic activities in the basins indicates that the natural disintegration of even igneous rocks containing metals does not pose a threat to the quality of water and the sediments. However, in the event of urbanized areas entering the basin, their influence on the use of sediments can be significant.

ACKNOWLEDGEMENT

This research was funded by the Scientific Grant Agency, grant number VEGA 1/0681/24.

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WPŁYW MATERIAŁU (RUMOWISKA) DENNEGO DOPŁYWÓW NA OSADY DENNE ZBIORNIKÓW WODNYCH KUČIŠDORF I HARMÓNIA

ABSTRAKT

Cel badań
Celem niniejszych badań była analiza obecności pierwiastków metalicznych w osadach dennych zbiorników wodnych zasilanych przez potoki spływające z pasm górskich, zawierające metale, oraz porównanie ich ze składem materiału dennego dopływów stanowiącego część skały macierzystej, w szczególności Fe, Zn, As, Sr, Zr, Al i Ni. Kolejnym krokiem było określenie sposobu transportu tych pierwiastków w korytach potoków oraz ich późniejszej akumulacji w zbiorniku.

Materiał i metody
Badania przeprowadzono na dwóch zbiornikach wodnych: Kučišdorf w obszarze katastralnym Pezinok i Harmónia w obszarze katastralnym Modra. Oba zbiorniki wodne służą głównie rekreacji i wędkarstwu sportowemu. Próbki pobrano w 2024 roku, a następnie przeanalizowano w latach 2024 i 2025. Pobrany materiał przeanalizowano za pomocą przenośnego spektrometru fluorescencji rentgenowskiej (XRF), model Vanta. Z pięciu wykonanych analiz obliczono średnią arytmetyczną, która następnie została wykorzystana w ocenie końcowej. Wyniki opracowano za pomocą oprogramowania MS Excel.

Wyniki i wnioski
Wyniki badania wskazują, że materiał denny w osadach dennych dopływów i zbiorników zawiera szeroką gamę pierwiastków, w tym metali. Wykazano, że stężenia monitorowanych pierwiastków są dostarczane do osadów dennych głównie z materiału dennego dopływów (rumowiska dennego) oraz że pierwiastki te kumulują się w osadach.

Słowa kluczowe: materiał denny dopływów (rumowisko denne), zbiornik wodny, osady denne, metale, zlewnia