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Analysis of Heavy Metal Content in Soil and Plants in the Dumping Ground of Magnesite Mining Factory Jelšava-Lubeník (Slovakia)

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Abstract: A high content of heavy metals in the soil and plants of a magnesite mining area might cause serious damage to the environment and can be a threat to the health of the surrounding population. This paper presents the results of research that focused on analyzing the heavy metal content in soil and plants in the dumping grounds of the magnesite mining factory Jelšava-Lubeník (Slovakia). The analysis focused on the content of heavy metals in soil (X-ray fluorescence spectrometry, atomic absorption spectrometry), in plants (inductively coupled plasma mass spectrometry, inductively coupled plasma atomic emission spectrometry), and pH (1M KCl solution). The results showed that the soil in the study area was slightly acidic to strongly alkaline and the content of Cr, As, Mn, and Mg exceeded by several times the limit values for the Slovak Republic. The results of the hierarchical cluster analysis and the correlation analysis show that the grouped metals come from the same sources of pollution. The content of heavy metals in plants was high and the highest concentration was found in the roots of *Elytrigia repens* > *Agrostis stolonifera* > *Phragmites australis* and flowers of *Phragmites australis*. The findings confirmed the suitability of the used plants in the process of phytoextraction and phytostabilization. The acquired knowledge can help in planning and realization remediation measures and improve the state of the environment in areas exposed to magnesite mining.

Keywords: magnesite mining; heavy metals; pH; phytoremediation; *Elytrigia repens*; *Agrostis stolonifera*; *Phragmites australis*

1. Introduction

The contamination of soil with heavy metals is a serious environmental threat and one of the most pressing environmental problems in the world [1–4]. It is largely due to anthropogenic activities such as mining and processing of metal ores, burning of fossil fuels, the use of fertilizers including sewage sludge and pesticides, transport, and many other industrial processes [5]. Heavy metal content can be affected by the interaction of soil physicochemical properties such as soil pH, soil granularity [6,7], organic matter content, and heavy metal storage capacity, which play an important role in the retention, mobilization, and migration of heavy metals in soil [8]. Environmental pollution from mining activities causes environmental and social problems. There is growing evidence that heavy metal pollution in mining areas has caused damage to the health of the local people [9–12] as well as damage to soil health [13,14]. The condition of the soil has a clear impact on the quality of the environment [15,16]. In recent years, the impact of heavy metals on soil ecosystems and human health has received increasing attention [17].

Slovak magnesite deposits are the largest and most important in Europe. A major part of the production is done by the Slovak magnesite factory, Jelšava, followed by Slovmag, Lubeník. Proven reserves at the current rate of mining ensure the production in Jelšava would last for over 100 years and in Lubeník for 10–15 years [18]. Extensive mining of

magnesite in the mentioned locality also has negative consequences. It is mainly the chemical degradation of the soil [19]. Raman et al. [20], Machin and Navas [21], Kautz et al. [22], and Wang et al. [23] report that dust emissions containing large amounts of magnesium cause severe soil degradation. Owing to their specific composition, solid particles from magnesite processing significantly affect the composition of the dust fallout, especially near the production factories. After sedimentation, the dust fallout interacts with the soil and other components of the environment, and can directly affect their quality. In the case of long-term operations, it strongly affects the environment [24]. Fazekas et al. [25] point out that the Jelšava-Lubeník area is one of the most devastated regions of Slovakia, with an alarming degree of environmental damage. The main component of environmental pollution in Jelšava-Lubeník is magnesite powder originating from aerosol particles. After being released into the environment, heavy metals can persist for centuries or even millennia, spread to distant areas, and accumulate in the biotic and abiotic components of ecosystems [26,27]. Therefore, they may adversely affect human health and ecosystems long after their release and far from their source [28–30].

It is very difficult to restore the soil environment if the soil is contaminated with heavy metals. Heavy metals in the soil also affect plant growth. Metals such as chromium (Cr), mercury (Hg), arsenic (As), lead (Pb), and cadmium (Cd) are toxic to most plants and other organisms at higher concentrations [31]. Cadmium is a highly toxic element that affects plant growth, metabolism, and condition [32]. Lead is not an essential element for plants; it tends to accumulate in plant roots and cause toxicity [33]. Zinc is an essential component for plants, but, in excessive amounts, it can cause toxicity [34]. Chromium is a toxic element for plants at concentrations higher than 0.50 mg/kg [35]. The distribution of contaminants in a plant is determined by the physiological character of the plant. Some plants tend to accumulate contaminants in certain organs. The distribution depends on the mobility of the contaminant in the plant tissues, on the type of plant, and the conditions of its growth [36]. Most plant species cannot adapt to a high level of heavy metal content, but some plants survive, grow, and reproduce in soils contaminated with heavy metals. A vast majority of these species tolerate heavy metal concentrations and retain most of the heavy metals in the roots with minimal translocation to the leaves. Hyperaccumulators show the opposite behavior concerning the absorption and the distribution of heavy metals in the plant [37]. Their activity consists of an active uptake of large amounts of heavy metals from the soil. Heavy metals are not retained in the roots, but translocated to other parts of the plant. Despite high concentrations of heavy metals, they do not show phytotoxicity [38]. Hyperaccumulators can accumulate metals at levels 100 times higher than those usually measured in non-accumulator plant shoots. The hyperaccumulator can concentrate more than 10 mg/kg of Hg; 100 mg/kg of Cd; 1000 mg/kg of Co, Cr, Cu, and Pb; and 10,000 mg/kg of Zn and Ni [39,40]. Some important hyperaccumulators according to Ma et al. [41], Schmidt [42], and Scragg [43] are *Thlaspi caerulescens*, *Alyssum murale*, *Brasica juncea*, *Betula pendula*, *Salix viminalis*, *Zea mays*, *Helianthus annuus*, *Agrostis capillaris*, *Agrostis stolonifera*, and *Pteris vittata*. Plants that are highly resistant to heavy metals include *Elytrigia repens* and *Taraxacum officinale* [44]. Several studies have confirmed that *Phragmites australis* is an important plant that can absorb heavy metals from the contaminated soil [25,45–48]. *Phragmites australis* can withstand extreme environmental conditions, including the presence of toxic contaminants such as heavy metals [45,46]. It can accumulate heavy metals in the individual parts of the plant in the order of manganese, zinc, lead, and copper. Concentrations in different parts of the plant vary. The highest content of these elements is concentrated in the roots, which indicates low mobility towards the aerial parts of the plant [47]. Although *Phragmites australis* is not a hyperaccumulator, several authors agree that it is appropriate to use it as an identifier for heavy metals and to detoxify contaminated environments [25,49–56]. *Elytrigia repens* and *Phragmites australis* have the potential to phytoextract and phytostabilize heavy metals Cr, Pb, Zn, Mn, Ni, and Cu present contaminated soils [57–60]. *Agrostis stolonifera* can accumulate heavy metals in the roots and is, therefore, recommended for phytostabilization [61–63]. Pérez-

de-mora et al. [64] found that *Agrostis stolonifera* can effectively reduce the concentration of soluble heavy metals and improve the diversity and structure of the microbial community in the soil. Numerous studies have suggested that *Elytrigia repens*, *Phragmites australis*, and *Agrostis stolonifera* are often used to remove extreme amounts of heavy metals from contaminated soil [65–68].

The main objective of the study is to quantify the content of heavy metals (Hg, Cd, Pb, Ni, Cr, Zn, Cu, As, Mn, Mg) in soils and underground and aerial parts of the dominant plant species (*Phragmites australis*, *Elytrigia repens*, *Agrostis stolonifera*) in the dumping ground of the magnesite factory Jelšava-Lubeník (Slovak magnesite factory Jelšava; Slovomag Lubeník; Slovakia).

2. Materials and Methods

2.1. Study Area

The research was conducted in the magnesium and other alkaline metals-rich areas, Jelšava (N48°38'39.1" E20°13'02.7") and Lubeník (N48°39'18.3" E20°11'48.9"). The investigated areas are located in the Revuca Highlands in the south-western part of the Slovak Ore Mountains [69]. The environmental regionalization of the Slovak Republic classifies the territory of Jelšava and Lubeník in the Revuca region of the 2nd environmental quality with a slightly disturbed environment. In this area, soils such as Rendzinas, Cambisols, and Luvisols predominate [70]. The climate in Jelšava-Lubeník is warm and slightly humid, with cold winters. The average temperature in winter is -3 to -5 °C, and in summer it ranges from 14.5 to 16.5 °C. The annual total precipitation is, on average, in the range of 700–800 mm [71].

2.2. Sampling Procedure

In the studied area, 12 regularly monitored sampling points, situated in the dumping ground of the magnesite factory, were located and recorded by GPS (Figure 1). The sampling points are used mainly as permanent grasslands. Soil samples were taken in September 2019 and 2020. Sampling was performed from soil horizon A, from a depth of 0.05 to 0.15 m, to quantify the heavy metal content and the pH. One homogeneous sample consisted of approximately 1 kg of soil from 5 different samples taken from points at regular distances in one sampling site. The soil samples were placed in labelled polyethylene bags, transported to the laboratory, and cleaned of plants and other materials. The individual samples were dried at room temperature, crushed, and sieved through a 2 mm stainless steel sieve. The underground and aerial parts of the dominant plant species *Phragmites australis*, *Agrostis stolonifera*, and *Elytrigia repens*, located in the mining dumping ground and forming monocultures, were investigated (Figure 2). The plant samples were taken in September 2020, placed in labelled polyethylene bags, transported to the laboratory, cleaned of residual materials, dried, and divided into individual parts (root, stem, flower) for further analysis. The sampling and processing procedures were in accordance with the Slovak standards STN ISO 10381 [72], and Decree No.338/2005 [73].

2.3. Analytical Methods

The total content of heavy metals in the soil was determined in cooperation with the State Geological Institute of Dionýz Štúr Spišská Nová Ves in an accredited geoanalytic laboratory (certificate no. 042/S-004) by X-ray fluorescence spectrometry (Cd, Pb, Cr, Zn, Cu, As, Ni, Mn, Mg) by SPECTRO XEPOS HE X-ray Spectrometer (SPECTRO ANALYTICAL INSTRUMENTS GmbH Germany) and X-ray tube VARIAN VF-60-W-S (W—Anode), and atomic absorption spectrometry (Hg) by AMA-254 Mercury Analyzer (ALTEC Prague). The content of heavy metals in plants was determined by inductively coupled plasma mass spectrometry (Cd, Pb) by AURORA M90 Spectrometer (BRUKER CAM Germany) and ICP MS 7900 (AGILENT USA) and inductively coupled plasma atomic emission spectrometry (Cr, Zn, Mn, Mg) by ICP OES 5100 and ICP OES 5110 Analyzers (AGILENT USA). The measured values were compared with the limit values set by the Act of the National Coun-

cil of the Slovak Republic No. 220/2004 Coll. [74]. The pH was determined in a 1M KCl solution (20 g of soil mixed with 50 ml of 1M KCl) using the pH meter, Mettler Toledo [75]. The correlations between pH and heavy metal content were analyzed using the Spearman correlation coefficient, Rho, with the help of IBM SPSS Statistics 26. Hierarchical cluster analysis was performed using PAST 4.

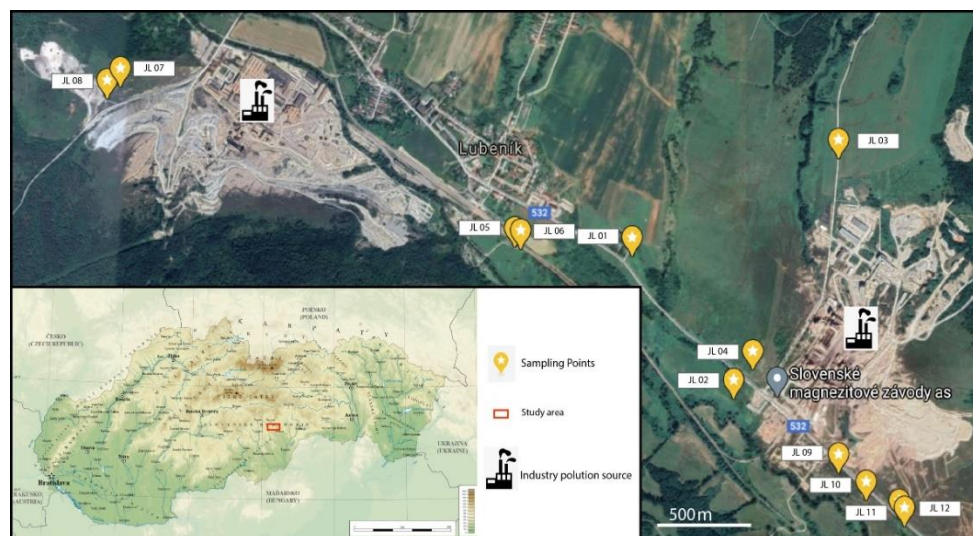


Figure 1. Location of sampling points in the dumping ground of the magnesite factory Jelšava-Lubeník (Slovakia).

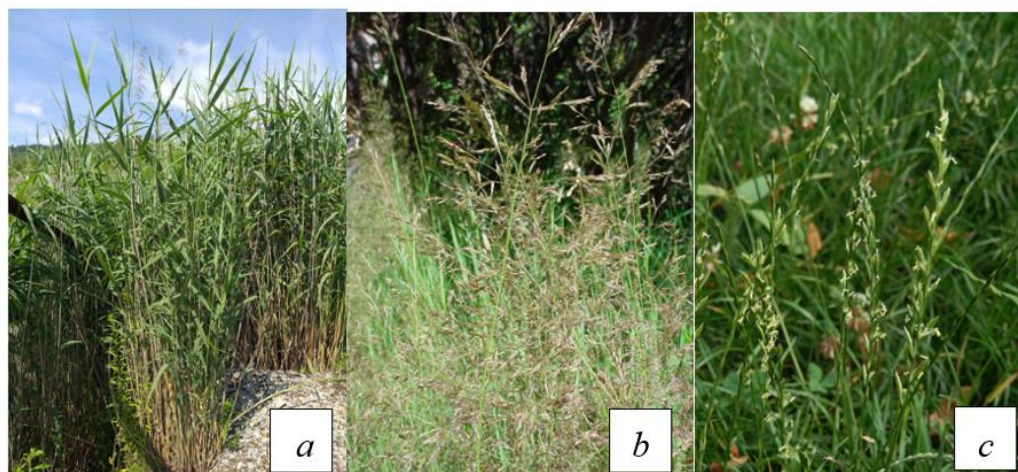


Figure 2. Dominant plant species in the dumping ground of the magnesite factory Jelšava-Lubeník (Slovakia): (a) *Phragmites australis*, (b) *Agrostis stolonifera*, (c) *Elytrigia repens*.

3. Results and Discussion

The pH is an important parameter in assessing the mobility and retention of heavy metals in soils [76]. The average pH value in the research area Jelšava-Lubeník reached the value of 8.05 in 2019 and 8.14 in 2020 (Table 1). The range of pH values was from 6.58 to 9.32, indicating that the soils in the study area are slightly acidic to strongly alkaline. The results of our research are consistent with the research of Yang et al. [77], who found that pH values in soils around magnesite mines were alkaline, ranging from 7.1 to 10.3. The strong alkalization of the soil in magnesite mining fields was also confirmed by a previous study by Hronec and Adamišín [78] and Fazekaš et al. [25]. Fluctuations of pH seem to be one of the most important factors influencing the mobility of the metals in the soil. Soil

acidity increases the absorption of heavy metals, while alkalinity of the soil may reduce the retention of heavy metals in soils [79].

The main cause of soil contamination in the Jelšava-Lubeník area is the mining and processing of magnesite. Table 1 shows the measured content of heavy metals in the soil and the pH in 2019 and 2020 expressed by descriptive statistics. The chromium content in the Jelšava-Lubeník area was in the range of 168.58 ± 197.86 mg/kg in 2019 and in the range of 152.83 ± 108.53 mg/kg in 2020, which exceeded the statutory limit. The median value of chromium in Slovak soils in the soil horizon A is around 85 mg/kg [80]. The highest measured chromium content exceeded the median value by almost 10 times. The content of arsenic in the soil exceeded the limit value of 25 mg/kg in both years. The average values of arsenic were 25.83 mg/kg in 2019 and 27.17 mg/kg in 2020. The toxic effects of Cd and As are potentially greater than those of other heavy metals [81,82], significantly increasing their environmental risks and the need to pay attention to remediation. The Act No. 220/2004 Coll. of Laws [74] does not set the limit values for the manganese and magnesium content in soil. The manganese content in 2019 was 1341.67 ± 505.35 mg/kg and 1266.67 ± 396.19 mg/kg in 2020, while the average manganese content in the soils of the Slovak Republic is in the range of 2.10–95.27 mg/kg [75]. Kabata-Pendias [5] states that if manganese values exceed 1500 mg/kg, toxicity can be reported. The measured values of magnesium in the research areas exceeded the average values for the Slovak Republic by several times. According to Kobza et al. [83], the average values of magnesium for the Slovak Republic were in the range of 200–400 mg/kg. The magnesium content in the Jelšava-Lubeník area reached values in the range of 8400–83,100 mg/kg. The highest measured value of magnesium exceeded the average value by 415 times. Based on significant differences between the measured values, it is possible to state that there is heterogeneity in the concentration of magnesium in the investigated localities. Fazekas et al. [25] found a significant level of soil contamination by magnesium in the study area, the values of which were in the range of $26,150 \pm 59,039$ mg/kg, representing an average excess that is 18 to 493 times higher. The result is secondary salinization with magnesium, chemical toxicity, and soil degradation. The area near the magnesite factory is made toxic by magnesite waste and is referred to as the lunar landscape, as a crust of $\text{Mg}(\text{OH})_2$ -brucite has formed on the upper part of the soil. Heavy metals are released into the atmosphere by emissions, are transported, and are further concentrated in crusts, extending them and not allowing vegetation to grow [25,84,85]. Huge heaps have formed around the factory as a result of the mining of magnesite over a long time (Figure 3); still, more and more heavy metals are released into the surrounding areas.



Figure 3. Area near magnesite factory Jelšava-Lubeník (Slovakia); (a) crust $\text{Mg}(\text{OH})_2$ formed by magnesite dust particles; (b) magnesite heap.

The content of mercury, cadmium, lead, zinc, copper, and nickel in the research areas did not exceed the values set by law [74]. Mean mercury values ranged from 0.01 to 0.14 mg/kg. The results of the Geochemical Atlas of the Slovak Republic [86] show that

Hg is present in the parent rock in the amount of 0.049–0.055 mg/kg. Therefore, similar values were expected and finally confirmed. The median cadmium value was 0.40 mg/kg. The average lead content was at the level of 29.92 mg/kg in 2019 and 28.90 mg/kg in 2020. Zinc reached values in the range of 52.00–113.00 mg/kg in the monitored years. The average copper content was 27.58 mg/kg in 2019 and 27.17 mg/kg in 2020. The average nickel content in the soil in 2019 was 32.58 mg/kg, and 31.92 mg/kg in 2020. Based on this data, it can be stated that the content of Hg, Cd, Pb, Zn, Cu, and Ni is below the level of harmfulness and toxicity in the investigated area.

In magnesium mining areas, high magnesium content in the soil has been confirmed, caused by the accumulation and deposition of magnesite dust, which increases soil degradation [23,77]. On the other hand, there are few studies that address the remediation of magnesium-contaminated soils. These facts have been confirmed in their studies by Raman et al. [20], Machin and Navas [21], Kautz et al. [22], and Wang et al. [23].

Table 1. Measured content of heavy metals in soil (mg/kg) and pH/KCl in the area Jelšava-Lubeník (Slovakia) expressed by descriptive statistics.

Year	Parameter	Mean	Median	Minimum	Maximum	Standard Deviation	Limit Value *
2019	pH/KCl	8.05	7.63	6.58	9.27	0.97	-
	Cr	168.58	104.50	85.00	793.00	197.86	70.00
	As	25.83	21.00	13.00	63.00	14.31	25.00
	Mn	1341.67	1350.00	400.00	2200.00	505.35	-
	Mg	31,500.00	18,350.00	9800.00	83,100.00	25,749.07	-
	Hg	0.07	0.07	0.01	0.14	0.03	0.50
	Cd	0.52	0.40	0.40	1.00	0.19	0.70
	Pb	29.92	30.50	22.00	45.00	6.86	70.00
	Zn	84.17	77.50	61.00	113.00	16.02	150.00
	Cu	27.58	28.00	16.00	45.00	9.28	60.00
	Ni	32.58	30.50	21.00	54.00	10.07	50.00
2020	pH/KCl	8.14	7.90	6.73	9.32	0.95	-
	Cr	152.83	102.50	78.00	377.00	108.53	70.00
	As	27.92	21.50	11.00	84.00	20.45	25.00
	Mn	1266.67	1300.00	600.00	1900.00	396.19	-
	Mg	24,891.67	19,200.00	8400.00	57,200.00	17,033.73	-
	Hg	0.07	0.06	0.03	0.10	0.03	0.50
	Cd	0.40	0.40	0.40	0.40	0.00	0.70
	Pb	28.92	29.50	16.00	39.00	7.61	70.00
	Zn	81.83	82.00	52.00	108.00	13.59	150.00
	Cu	27.17	27.00	13.00	49.00	12.04	60.00
	Ni	31.92	28.50	19.00	47.00	9.77	50.00

Note: * Act No. 220/2004 Coll. of Laws.

A correlation matrix, showing the relationships between heavy metals and pH at the significance level $p < 0.05$ and $p < 0.01$, is shown in Table 2. Based on the Spearman correlation coefficient, Rho, positive significant correlations were found between Zn-Cr, Cu-As, Ni-Cu, and Ni-As, and a single negative significant correlation between Cu-Pb, which is consistent with the results of the study by Zhang et al. [85], who studied heavy metal content in farmland soil in the context of human activities of mining and smelting, industry, irrigation by sewage, urban development, and fertilizer application. Furthermore, positive correlations were found between Hg-Mn, Mg-Cu and Cu-As, pH-Cu, pH-Mn, and pH-Mg. The positive significant relationship between pH and Mg in magnesite soils is also confirmed by Yang et al. [77], who studied soil chemical and microbial properties among mine tailings, abandoned mined land, contaminated cropland, and uncontaminated cropland around a magnesite mine, and clarified the impact of Mg on the soils. High correlation coefficients between heavy metals may indicate that metals have a similar origin of pollution sources and their presence reflects anthropogenic inputs from industrial activities. They can be characterized by a similar process of migration and transformation

through physicochemical conditions in the environment. On the contrary, low or negative correlation coefficients may indicate different sources that are related to natural or geogenic processes [87,88].

The dendrogram of the hierarchical cluster analysis is shown in Figure 4. The metals included in the group come from the same polluting source. The first group consisted of Cd-Hg, the second group of Mn-Mg, the third group of Zn-Cr, and the fourth group of Pb-Cu, Ni, and As. The results of the hierarchical cluster analysis and the correlation analysis show that the grouped metals come from the same sources of pollution. The high content of Mg and Mn could come not only from the weathering of the basic materials, but is related mainly to the intensity of mining and processing of magnesite. Similar findings are presented in the work by Doležalová [88]. In our case, the amount of heavy metals in the soil forms the so-called natural background related mainly to the weathering of the rocks. However, the overall content of these elements is decisively influenced by the anthropogenic activity, which is pointed out in the work of Dercová et al. [89] and Sun et al. [90].

Table 2. Correlation matrix (Spearman's Rho) between heavy metals and pH/KCl in the area Jelšava-Lubeník (Slovakia).

Parameter	Cd	Pb	Cr	Zn	Cu	As	Ni	Mn	Mg	pH/KCl
Hg	0.044	0.559	−0.252	−0.355	−0.315	−0.282	−0.354	0.633 *	−0.090	0.115
Cd		0.004	0.143	0.344	0.345	0.485	0.376	0.196	0.152	0.231
Pb			−0.343	−0.364	−0.656 *	−0.551	−0.501	0.139	−0.466	−0.228
Cr				0.582 *	0.042	0.111	0.056	−0.474	−0.168	−0.509
Zn					0.316	0.420	0.284	−0.186	0.245	−0.329
Cu						0.924 **	0.924 **	0.259	0.723 **	0.586 *
As							0.935 **	0.234	0.581 *	0.420
Ni								0.155	0.470	0.393
Mn									0.531	0.594 *
Mg										0.762 **

Note: * $p < 0.05$, ** $p < 0.01$.

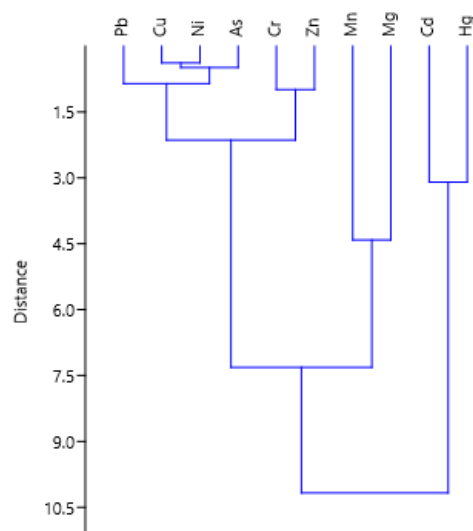
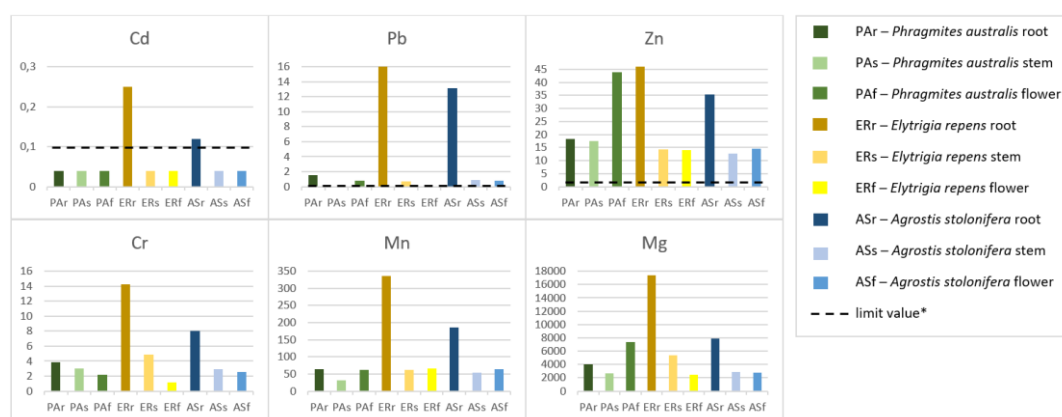


Figure 4. Dendrogram of the heavy metal contents in the soils from hierarchical cluster analysis.

The content of heavy metals in the underground and aerial parts of *Phragmites australis*, *Elytrigia repens*, and *Agrostis stolonifera* is shown in Figure 5. Cadmium values exceeded the limit values in the roots of *Elytrigia repens* (0.25 mg/kg of dry matter) > *Agrostis stolonifera* (0.12 mg/kg of dry matter). The lead concentration exceeded the legal values in all examined plants except for the stem of *Phragmites australis* and the flower of *Elytrigia repens*. Extremely high lead concentrations were found in the roots of *Elytrigia repens* (16.20 mg/kg of dry

matter) > *Agrostis stolonifera* (13.10 mg/kg of dry matter). Some hyperaccumulators can accumulate up to 10,000 mg/kg of zinc [91]. The limit value for zinc was exceeded in all examined plants, with the highest content in the root of *Elytrigia repens* (46.00 mg/kg of dry matter) > flower of *Phragmites australis* (43.90 mg/kg of dry matter) > root of *Agrostis stolonifera* (35.30 mg/kg of dry matter). Zinc concentrations ranged from 12.70 to 46.00 mg/kg of dry matter. The high content of zinc in *Phragmites australis* was pointed out by Bonanno and Giudice [47], Lesage et al. [92], and Vymazal et al. [93]. The measured values of chromium ranged from 1.20 to 14.30 mg/kg of dry matter. High chromium content was recorded in the roots of *Elytrigia repens* (14.30 mg/kg of dry matter) > *Agrostis stolonifera* (8.00 mg/kg of dry matter). Similar results for the heavy metal content (Cr, Cd, Pb) in *Elytrigia repens* were confirmed in the studies of Minkina et al. [57] and Chaplygin et al. [94]. High concentrations of manganese and magnesium were measured in all parts of the plants. Plants can accumulate manganese, especially in the roots. In general, plants are affected by 500 mg/kg of manganese content. In some parts, resistant hyperaccumulators can accumulate 1000–10,000 mg/kg of manganese [95]. Manganese values ranged from 64.00 ± 97.83 mg/kg of dry matter, with the highest content found in the roots of *Elytrigia repens* (337.00 mg/kg of dry matter) > *Agrostis stolonifera* (185.00 mg/kg of dry matter) > *Phragmites australis* (64.00 mg/kg of dry matter). Plants growing on magnesium-contaminated soil having a concentration of 5000 mg/kg show signs of toxicity within 12 days. Plants that receive 10,000 mg/kg of magnesium show signs of toxicity within 5 days [96]. The average concentration of magnesium in the plants was 5863.33 mg/kg of dry matter. The highest content was measured in the roots of *Elytrigia repens* (17,400 mg/kg of dry matter) > roots of *Agrostis stolonifera* (7870 mg/kg of dry matter) > *Phragmites australis* (7340 mg/kg of dry matter). The high content of Mg in *Elytrigia repens*, *Agrostis stolonifera*, and *Phragmites australis* near magnesite mining areas was confirmed in the studies of Zelenáková et al. [97], Hronec and Hajdúk [98], and Blanár [99]. It can be stated that the content of Cd, Pb, Zn, Cr, Mn, and Mg in plants was high, and the highest concentration was found in the roots of *Elytrigia repens* > *Agrostis stolonifera* > *Phragmites australis* and the flowers of *Phragmites australis* (Zn, Mg).

The results showed that the monitored dominant plant species can accumulate heavy metals without serious damage to their metabolism. At the same time, we can state that the monitored plant species are applied in places with surface pollution. The mechanism, or tolerance, to heavy metals is described in detail in Dercová [89] and Zwolak [100]. In our case, *Phragmites australis* appears to be effective in the process of phytoextraction, which not only has the ability to accumulate hazardous soil elements through its root system, but also to transport and store them in the aboveground biomass. At the same time, our results show that the highest content of difficult-to-extract heavy metals, especially Pb, was found in the roots of *Elytrigia repens* and *Agrostis stolonifera*, thus confirming the suitability of these plant species in the phytostabilization process.



Note: * Act No. 220/2004 Coll. of Laws.

Figure 5. Content of heavy metals (mg/kg) in underground and aerial parts of plants in the area Jelšava-Lubeník (Slovakia).

4. Conclusions

This paper presents the results of research on the content of heavy metals in soils and plants in the waste dumping ground of the magnesite factory Jelšava-Lubeník (Slovakia). The main component of environmental pollution in Jelšava-Lubeník is magnesite powder originating from aerosol particles. Based on the results of the research, it can be stated that the soils in the investigated area are slightly acidic to strongly alkaline. The soils in the dumping ground of the magnesite factory Jelšava-Lubeník are contaminated with heavy metals, especially Cr, As, Mn, and Mg. In selected areas, the measured values exceeded the limit values set by law, such as the average values for soils of the Slovak Republic. The results of the hierarchical cluster analysis and the correlation analysis show that the grouped metals come from the same sources of pollution. The high content of Mg and Mn could come not only from the weathering of the basic materials, but is related mainly to the intensity of mining and processing of magnesite. The content of heavy metals (Cd, Pb, Zn, Cr, Mn, Mg) in plants was high and the highest concentration was found in the roots of *Elytrigia repens* > *Agrostis stolonifera* > *Phragmites australis* and the flowers of *Phragmites australis* (Zn, Mg). These findings show that *Phragmites australis* appears to be effective in the process of phytoextraction, and *Elytrigia repens* and *Agrostis stolonifera* in the process of phytostabilization. Heavy metals present in the soils and plants of the Jelšava-Lubeník magnesite mining area cause serious damage to the environment, with a possible impact on the health of the population. The acquired knowledge about the content of heavy metals in soil and plants in the waste dumping ground of the magnesite factory Jelšava-Lubeník (Slovakia) can help in planning and realization remediation measures, strengthening the control and management of active mining and industrial areas. At the same time, it would prevent the spread of heavy metals into the environment and contribute to improvement the state of the environment in areas exposed to magnesite mining.

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