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THE POTENTIAL IMPACT OF LANDFILL ON THE NEAR VICINITY WITH THE USE OF HEAVY-METAL ACCUMULATOR PLANTS

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Abstract

This study was conducted to screen plants growing on potentially contaminated areas of landfill body and nearest surrounding to determine their potential for metal accumulation. In addition, enrichment coefficient (*EC*) for plant/soil system, correlation and principal component analysis were used for determining the environmental contamination from landfill in terms of heavy metal (HM) accumulation. The examined plant samples meet the stated requirements. The highest values in samples 1 - 8 reached Fe (491 – 191 000 mg/kg DM), the second values were Mn (35.1 – 342 mg/kg DM) and the third was Zn (26.9 – 145 mg/kg DM). The highest concentrations of Co, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn were observed (in order) in plant samples 4, 2 and 1, i.e. plants collected in the vicinity of the landfill. The examined soil samples meet the stated requirements. The highest values in samples 1 - 8 reached Fe (23 300 to 63 400 mg/kg DM), the second were recorded for Mn (527-908 mg/kg DM) and the third was Zn (83.0 - 519 mg/kg DM). The highest concentrations of Co, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn were observed (in order) in soil samples 7, 2 and 5. *EC* was calculated for all 8 sampling points. The highest degree of accumulation was observed for Cd in all 8 sampling points. In contrast, the lowest concentration of all the examined heavy metals was determined for Cd in plant and soil samples.

Key words: enrichment coefficient, landfill, metal accumulation, *Tanacetum vulgare* L., waste

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1. Introduction

1.1. Landfill – an option for the management of municipal solid waste

Landfill disposal remains the main option for the management of municipal solid waste (MSW) not only in the Czech Republic (CR) but worldwide (Jones et al., 2013; Koda et al., 2016; Grzesik and Malinowski, 2017; Turan et al., 2016). Landfills have been used for the disposal of MSW as well as industrial waste for decades (Koda et al., 2013). This alternative has been applied for waste which cannot be recovered or treated in another way. Though waste is kept in a long-term relatively safe way and landfilling is controlled by a strict regulatory framework, this alternative is a potential source of pollution and hazardous substances (Adamcová et al., 2017). Landfills can be a source of a large number of pollutants and compounds diffuse through air or leachate release. Some research has been shown that landfills spreads compounds that accumulated in the soil and may be available for the species even at considerable distances from the source (Koda and Osiński, 2017; Mazzeo et al., 2013, Vaverková et al., 2018).

The landfill can be considered as a complex environment where many interacting physical, chemical and biological processes take place (Ozkaya et al., 2006; Koda et al., 2016). The degradation

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process of MSW in landfills is a long-term event (Vaverková and Adamcová, 2018), therefore, emissions will have to be managed for years, contradicting the principles of sustainability (Fellner and Brunner, 2010).

There are many studies on the chemical characterization of leachate but they represent only the first step for a meaningful environmental impact evaluation. For these reasons one of the most important activities concerning the management of the MSW landfill regards the control and environmental monitoring aimed to safeguard both of the structural aspects of the plant (i.e., efficiency) both the environmental quality of the site. Quantification of heavy elements levels in soil and air cannot generate sufficient information on impact because the absolute metal concentration alone does not reflect the degree to which these compounds affect the environment (Mazzeo et al., 2013). Data on the bioaccumulation and effects of leachate on wild populations are essential to assess the environmental impact of these disposal sites (Mazzeo et al., 2013; Vaverková et al., 2018).

1.2. Nature of the problem

The presence of metals in soils is related with natural factors such as geographic location, type of soil, oxidation–reduction potential, cation exchange capacity, clay content, nature of drainage waters and type of plants grown in those soils (Elbl et al., 2014; Vaverková et al., 2018). However, anthropogenic inputs associated with agricultural practices, mineral exploration, industrial processes and waste management (WM) are important contributors to heavy metal (HM) contamination of natural ecosystems. The persistence of HM in soils is a significant environmental problem (Wyszkowski and Radziemska, 2009). Plants interact with their local environment, namely air, water and soil. The most dangerous and prevailing contaminants include HM (Kabata-Pendias and Pendias, 1999). Their high concentrations of HM in the soil negative effects on the growth and development of plants, evoking disturbances in the absorption, transport and assimilation of individual elements and contributing to changes fluctuating contents of some micro- and macro elements (Wyszkowski and Radziemska, 2009).

Zinc and copper belong to the group of elements whose minimal doses are indispensable for the proper functioning of organisms and excessive amounts exert detrimental effects (Pederson et al., 2002; Stevovi et al., 2010). Plants usually demonstrate a high tolerance towards increased contents of HM, however, excessive concentrations of HM in the soil are harmful to plants due to the ease of their accumulation (Vaverková at al., 2018). Tansy plant (*Tanacetum vulgare* L.) is a common and wide spread plant in CR. It can be cultivated, and it also grows spontaneously. *Tanacetum vulgare* L. (*T. vulgare*) was selected for laboratory research since it belongs to ruderal and common flora where the imperative to adapt is high. Production of essential oil by *T. vulgare* is an indicator of plant adaptation on habitat conditions (Stevovic et al., 2009). Ecological role of essential oils is reflected in the interaction of plants with environmental factors. It helps plant to easily adapt to the environmental stress conditions: drought, intense radiation, high temperature and HM contents (Abu-Darwish and Abu-Dieyeh, 2009).

Our research team has been involved in the investigation of environmental problems of pollutants produced and released from landfill facilities. As part of such research efforts, a preliminary study was conducted to measure the emission concentrations from MSW landfill Štěpánovice as well as biological monitoring with the use of bioindicators. In this paper we propose an evaluation method to determine the degree of environmental contamination by the contest of HM in soil and *T. vulgare* on two site locations. One was landfill body and the other the nearest landfill surrounding.

2. Experimental

2.1. Study area

The investigated landfill (Štěpánovice, 49°26'15.934"N, 13°16'55.352"E) is located in Pilsen Region, western part of the CR, 1 km north of Štěpánovice commune and 1 km south of Dehtín commune. It started operating during 1996 with an authorized volume of 569000 m^3, at the moment, it is being used to dispose mixed MSW. The landfill is formed by three sub-landfills: landfill A (closed in 2003, area 8750 m^2); landfill B (working from 2003, area 26000 m^2); landfill C. The total volume of both (A, B) parts of the landfill is 289000 m^3. Planned service life of the facility is up to year 2024.

Every day, up to 37.5 tons of waste is authorized for landfilling after careful analysis: the disposed waste includes MSW, non-hazardous wastes and the material for landfill cover. Wastes may include scraps of paper, plastics and metals, packing, spent tires, textile products, building materials, ashes from MSW incinerators, polluted terrain from environment reclamation etc. Particular details of waste composition, waste quantity stored on landfill and landfill gas management are not presented in this article.

The landfill site is located over an impermeable natural clay layer; bottom and side boundaries may vary according to the period of cultivation, however they include several protective layers, such as a compact clay layer (100 cm), geotextile membranes, gravel (50 cm), geomembranes (2.5 mm) non-woven fabric (1200 g/m^2), pulper products (50 cm).

Landfill covers (top and side) are formed by a waste layer (terrain) to stabilize the surface, drainage systems, compact clay (20 cm), soil bentonite and a vegetative soil layer (up to 100 cm). A grassy mantle and/or forestation with local vegetation will complete the recovery of the environment after closing of each

parcel. Systems for leachate treatment, and gas recovery, collection and treatment are in operation. The landfill is surrounded to the N and S by a vegetation belt dominated by *Pinus sylvestris*. The hilly landscape in the western part of the study area is used for agriculture, as well as the eastern lowland. The climate of the area is typically inland, with mean annual rainfall over 582 mm and mean annual temperature of 8.0°C.

2.2. Sample collection

Whole *T. vulgare* samples were collected from two different ecological habitats: landfill body (two samples) and landfill surrounding (six samples) (Fig. 1). Height of the plants ranged from 30 to 60 cm at the time of harvest. *T. vulgare* was growing on waste materials on landfill and in the nearest landfill surrounding. Plant materials were harvested at the end of May. *T. vulgare* were uprooted, labeled and taken to the laboratory for the analysis. Fresh plant material was air dried between the sheets of porous paper, for about a month. Dried samples were ground to fine powder using pestle and mortar and then were chemically analyzed for the content of HM (Co, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn).

The soils were sampled at 0 - 15 cm depths under the *T. vulgare* roots and transferred into well labeled polyethylene bags for storage and laboratory analyses (Fig. 2). Soil samples were dried at the temperature 105 °C until constant weight, ground to fine powder and homogenized. The samples were collected from 8 different places of both site localities. The materials were analyzed for the content of HM (Co, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn). The chemical analysis was performed by microwave decomposition in the *aqua regia* medium, followed by spectrometric analysis.

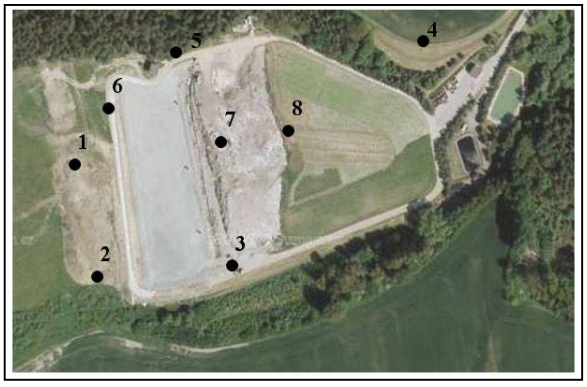

Fig. 1. Sampling points (www.maps.google.com)

Fig. 1 provides sampling points where soil and plant samples were collected. In total 8 sampling points were determined. Samples collected from sampling points 1, 2 and 4 were used as blind samples. Samples from sampling points 7 and 8 were collected directly from the landfill body and samples 3, 5 and 6 were taken from the edge of the landfill body. The allocation of sampling sites was chosen on the basis of the authors` decision and on the grounds of mutual comparison of the landfill body and its borders with the nearest vicinity of the landfill (agriculturally utilized soil and forests). Fig. 2 illustrates soil and plant samples.

Fig. 2. Samples of Tansy plant (*Tanacetum vulgare* L.)

The examined samples were brought to the accredited testing laboratory for analyses. The samples were analyzed for the content of HM (Co, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn). Concentration of HM was analyzed according to ČSN EN ISO 11885. For the determination of the contents of HM, the samples were mineralized by microwave digestion with HNO_3 and H_2O_2.

2.3. Statistical analysis

A one-way ANOVA was performed to reveal the differences between HM concentrations of samples from land-fill body and land-fill surrounding, using STATISTICA 10.0 software (www.StatSoft.com). After obtaining significant ANOVA results, a Tukey HSD post hoc test was applied to determine significant differences between ecological habitats.

2.4. Enrichment coefficient for plant / soil system

Enrichment coefficient (*EC*) was calculated to assess the accumulations of HM from soils to plants, and it is described as the following formula (Chao et al., 2007; Kachenko and Singh, 2006) (Eq. 1):

$$EC = M_{plant} / M_{soil} \quad (1)$$

where: *EC* is the enrichment coefficient for plant/soil system; M_{plant} - is the concentration of a metal in the tissue of plant (root or leaf), mg/kg, in dry matter; M_{soil} - is the total concentrations of a metal in soils where this plant is grown, mg/kg, in dry matter.

3. Results

The soil and plant samples collected and were analyzed for HM contents. It appears that HM concentration in different samples varies to a great extent from sample to sample.

The following tables (Tables 1 - 16) are the results of the analysis of HM in samples of plants (Tables 1 - 8) and soils (Tables 9 - 16). Results for Sample no. Plant 1 (labelled in the laboratory as B9981) are presented in Table 1.

Results for Sample no. Plant 2 (labelled in the laboratory as B9982) are presented in Table 2. Results for Sample no. Plant 3 (labelled in the laboratory as B9983) are presented in Table 3. Results for Sample no. Plant 4 (labelled in the laboratory as B9984) are presented in Table 4. Results for Sample no. Plant 5 (labelled in the laboratory as B9985) are presented in Table 5. Results for Sample no. Plant 6 (labelled in the laboratory as B9986) are presented in Table 6. Results for Sample no. Plant 7 (labelled in the laboratory as B9987) are presented in Table 7. Results for Sample no. Plant 8 (labelled in the laboratory as B9988) are presented in Table 8. Results for Sample no. Soil 1 (labelled in the laboratory as B9973) are presented in Table 9. Results for Sample no. Soil 2 (labelled in the laboratory as B9974) are presented in Table 10. Results for Sample no. Soil 3 (labelled in the laboratory as B9975) are presented in Table 11. Results for Sample no. Soil 4 (labelled in the laboratory as B9976) are presented in Table 12. Results for Sample no. Soil 5 (labelled in the laboratory as B9977) are presented in Table 13. Results for Sample no. Soil 6 (labelled in the laboratory as B9978) are presented in Table 14. Results for Sample no. Soil 7 (labelled in the laboratory as B9979) are presented in Table 15. Results for Sample no. Soil 8 (labelled in the laboratory as B9980) are presented in Table 16.

Table 1. Results for Sample no. Plant 1

Parameter	*Unit*	*Sample no.B9981*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)**	%	94.00	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	3.45	20%	ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	0.83	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	24.40	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	14.90	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	6050.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	188.00	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	5.56	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	5.00		ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	30.30	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*
*** Dry mass (DM)*

Table 2. Results for Sample no. Plant 2

Parameter	*Unit*	*Sample no.B9982*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	94.46	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	10.30	20%	ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	0.73	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	50.40	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	36.90	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	19100.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	342.00	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	23.30	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	5.49	20%	ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	60.00	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

Table 3. Results for Sample no. Plant 3

Parameter	*Unit*	*Sample no.B9983*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	92.81	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	3.00		ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	2.09	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	6.22	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	13.00	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	1770.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	77.50	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	5.70	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	5.00		ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	45.10	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

Table 4. Results for Sample no. Plant 4

Parameter	*Unit*	*Sample no.B9984*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	92.88	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	3.00		ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	5.08	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	3.41	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	15.10	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	1160.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	326.00	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	9.91	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	5.00		ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	58.80	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

Table 5. Results for Sample no. Plant 5

Parameter	*Unit*	*Sample no.B9985*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	92.80	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	3.00		ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	1.66	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	3.00		ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	14.00	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	491.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	35.10	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	3.14	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	5.00		ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	28.70	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

Table 6. Results for Sample no. Plant 6

Parameter	*Unit*	*Sample no.B9986*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	92.55	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	3.00		ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	1.15	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	3.33	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	17.60	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	684.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	69.30	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	7.21	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	5.00		ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	26.90	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

Table 7. Results for Sample no. Plant 7

Parameter	*Unit*	*Sample no.B9987*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	92.56	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	3.00		ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	1.45	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	3.00		ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	13.40	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	924.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	73.10	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	2.19	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	5.00		ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	145.00	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

Based on the measured values, the results of all 16 examined samples (8 samples of plants and 8 samples of soils) were subjected to a mutual comparison. Fig. 3 shows the comparison of samples of plants 1-8 according to the parameter of HM (Co, Cd, Cr, Cu, Mn, Ni, Pb and Zn). For clarity Fe is separately shown on Fig. 4. All examined soil samples meet the stated requirements. Nevertheless, there are differences among some of the sample values. The highest values in samples 1 - 8 reached Fe (491 – 191 000 mg/kg DM), the second highest values were recorded for Mn (35.1 – 342 mg/kg DM) and the third

was Zn (26.9 – 145 mg/kg DM). The highest concentrations of heavy metals (Co, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) were observed (in order) in soil samples 4, 2 and 1, i.e. plants collected in the vicinity of the landfill.

Fig. 5 shows the comparison of soil samples 1-8 according to the parameter of heavy metals (Co, Cd, Cr, Cu, Mn, Ni, Pb and Zn). For clarity Fe is separately shown on Fig. 6. The concentration of Cd in soil samples ranged from 0.25 to 1.83 mg/kg DM.

Table 8. Results for Sample no. Plant 8

Parameter	*Unit*	*Sample no.B9988*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	92.25	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	3.00		ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	0.64	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	10.70	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	10.80	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	2620.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	115.00	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	5.80	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	5.00		ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	45.50	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

Table 9. Results for Sample no. Soil 1

Parameter	*Unit*	*Sample no.B9973*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	97.43	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	17.40	20%	ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	0.27	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	56.00	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	46.10	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	31700.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	781.00	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	31.50	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	20.90	20%	ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	83.50	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

Table 10. Results for Sample no. Soil 2

Parameter	*Unit*	*Sample no.B9974*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	97.47	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	22.70	20%	ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	0.38	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	80.90	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	74.20	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	42800.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	773.00	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	52.50	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	16.20	20%	ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	110.00	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

Table 11. Results for Sample no. Soil 3

Parameter	*Unit*	*Sample no.B9975*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	99.21	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	14.50	20%	ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	0.44	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	50.60	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	41.10	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	23300.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	527.00	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	33.10	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	28.60	20%	ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	197.00	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

Table 12. Results for Sample no. Soil 4

Parameter	*Unit*	*Sample no.B9976*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	98.69	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	11.30	20%	ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	0.25		ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	57.50	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	41.30	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	37100.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	862.00	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	17.30	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	14.60	20%	ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	65.70	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

Table 13. Results for Sample no. Soil 5

Parameter	*Unit*	*Sample no.B9977*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	98.67	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	22.40	20%	ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	0.38	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	61.60	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	55.60	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	34800.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	908.00	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	44.20	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	25.40	20%	ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	91.60	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

Table 14. Results for Sample no. Soil 6

Parameter	*Unit*	*Sample no.B9978*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	98.75	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	28.60	20%	ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	0.28	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	95.60	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	56.40	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	36300.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	634.00	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	79.50	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	22.90	20%	ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	92.70	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

Table 15. Results for Sample no. Soil 7

Parameter	*Unit*	*Sample no.B9979*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	98.20	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	14.10	20%	ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	1.83	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	86.90	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	170.00	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	63400.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	753.00	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	46.90	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	241.00	20%	ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	519.00	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

All examined soil samples meet the stated requirements. Nevertheless, there are differences among some of the sample values. The highest values in samples 1 - 8 reached Fe (23 300 to 63 400 mg/kg DM), the second highest values were recorded for Mn (527 - 908 mg/kg DM) and the third was Zn (83.0 - 519 mg/kg DM). The highest concentrations of HM (Co, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) were observed (in order) in soil samples 7, 2 and 5.

Table 16. Results for Sample no. Soil 8

Parameter	*Unit*	*Sample no.B9980*	*NM*	*Testing method identification*	*Accr.*
Dry mass (105°C)	%	97.57	10%	GRA 03A:ČSN 720102	A
Co	mg/kg DM	15.70	20%	ICP 04A:ČSN EN ISO 11885	A
Cd	mg/kg DM	0.25	20%	ICP 04A:ČSN EN ISO 11885	A
Cr	mg/kg DM	48.50	20%	ICP 04A:ČSN EN ISO 11885	A
Cu	mg/kg DM	32.90	20%	ICP 04A:ČSN EN ISO 11885	A
Fe	mg/kg DM	30200.00	20%	ICP 04A:ČSN EN ISO 11885	A
Mn	mg/kg DM	612.00	20%	ICP 04A:ČSN EN ISO 11885	A
Ni	mg/kg DM	25.70	20%	ICP 04A:ČSN EN ISO 11885	A
Pb	mg/kg DM	21.40	20%	ICP 04A:ČSN EN ISO 11885	A
Zn	mg/kg DM	83.00	20%	ICP 04A:ČSN EN ISO 11885	A

**(A) Accredited standard operating procedure, (N) Non-accredited standard operating procedure, (NM) Measurement uncertainty*

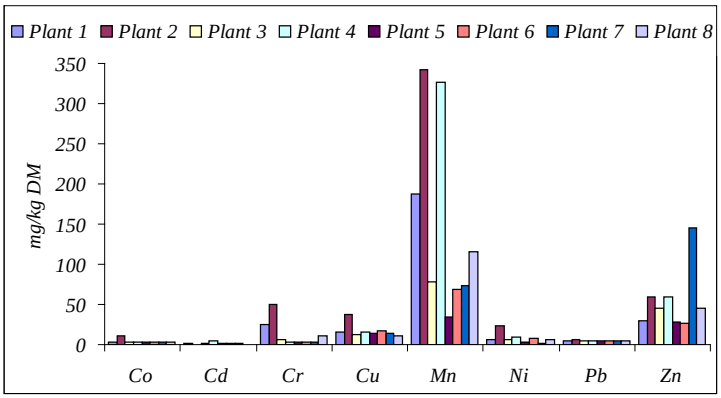

Fig. 3. Contents of HM (Co, Cd, Cr, Cu, Mn, Ni, Pb and Zn) in the samples 1 - 8 Plant (mg/kg DM)

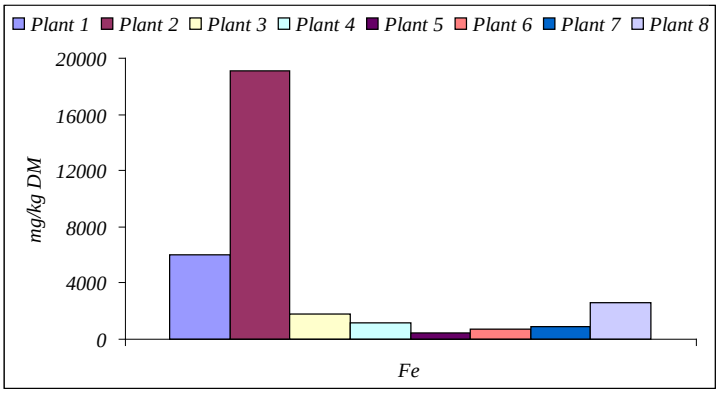

Fig. 4. Contents of HM (Fe) in the samples 1 - 8 Plant (mg/kg DM)

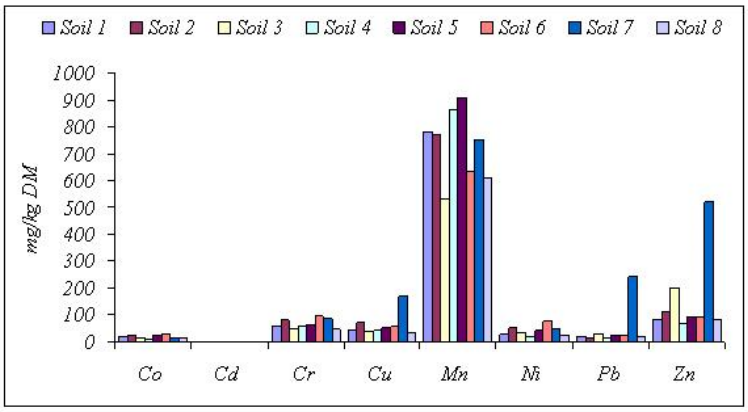

Fig. 5. Contents of HM (Co, Cd, Cr, Cu, Mn, Ni, Pb and Zn) in the samples 1 - 8 Soil (mg/kg DM)

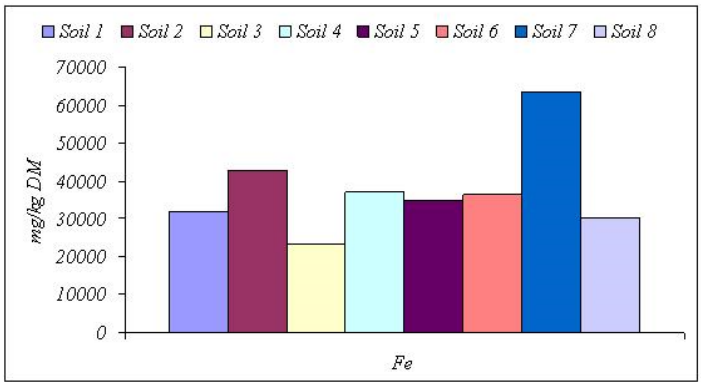

Fig. 6. Contents of HM (Fe) in the samples 1 - 8 Soil (mg/kg DM)

3.1. Plants analysis

The mean concentrations of Co, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn in plants from the surrounding and the body of the landfill are shown in the Fig. 7. Expect of Zn, the concentrations of all elements are higher in the surrounding of the landfill. Though, comparing the concentrations of HM between these two localities, no statistically significant differences were revealed in the case of Co (d. f. = 1, F = 0.345, p =0.578), Cd (d. f. = 1, F = 0.51, p = 0.502), Cr (d. f. = 1, F = 0.331, p = 0.586), Cu (d. f. = 1, F = 0.91, p = 0.378), Fe (d. f. = 1, F = 0.327, p = 0.588), Mn (d. f. = 1, F = 0.61, p = 0.465), Ni (d. f. = 1, F = 0.875, p = 0.386), Pb (d. f. = 1, F = 0.3, p = 0.604) and Zn (d. f. = 1, F = 4.23, p = 0.85).

The mean concentration of a) Co, b) Cd, c) Cr, d) Cu, e) Fe, f) Mn, g) Ni, h) Pb and i) Zi (mg/kg DM) in the plants from surrounding and the body of the landfill. Columns marked by the same letter were not significantly different at 0.05 probability level.

3.2. Soil analysis

Concentrations of trace elements in the soil from the surrounding and the body of the landfill are shown in the Fig. 8. According to ANOVA, no statistically significant differences were recorded between the body of the landfill and its surroundings in the case of Co (d. f. = 1, F = 0.345, p = 0.578), Cd (d. f. = 1, F = 3.517, p = 0.11), Cr (d. f. = 1, F = 0.51, p = 0.968), Cu (d. f. = 1, F = 2.121, p = 0.196), Fe (d. f. = 1, F = 1.83, p = 0.225), Mn (d. f. = 1, F = 0.34, p = 0.581), Ni (d. f. = 1, F = 0.16, p = 0.703), Pb (d. f. = 1, F = 4.45, p = 0.79) and Zn (d. f. = 1, F = 3.21, p = 0.123). The mean concentration of a) Co, b) Cd, c) Cr, d) Cu, e) Fe, f) Mn, g) Ni, h) Pb and i) Zn (mg/kg DM) in the plants from surrounding and the body of the landfill. Columns marked by the same letter were not significantly different at 0.05 probability level.

3.3. Enrichment Coefficient for Plant/Soil System

The results *of EC* for plant/soil system are shown in Fig. 9. Malayeri et al., (2008) grouped plant species according to their HM uptake capacities and sensitivity to metal pollution:

High accumulator plants - *EC* between 1-10
Moderately accumulator plants - *EC* between 0.1-1.0
Low accumulator plants - *EC* between 0.01-0.1
Non accumulator plants - *EC*< 0.01

The *highest EC* for all investigated *T. vulgare* was Cd (Fig. 9).

Fig. 9 illustrates graphical evaluation of the results for the *EC* values (mg/kg DM) in particular samples (samples 1 – 8) collected from sampling points (1 - 8).

In sample 1 the *EC* values for HM Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn were lower than 1.0 mg/kg DM, thus a moderate degree of accumulation. Only with regard to HM Cd the *EC* amounted to 3.074 mg/kg DM, i.e. *EC* > 1.0, a high level of accumulation.

As for sample 2 the *EC* values for HM Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn reached values lower than 1.0 mg/kg DM, thus a moderate degree of accumulation. Only Cd reached the *EC* value of 1.921 mg/kg DM, i.e. *EC* > 1.0, a high level of accumulation.

With regard to sample 3 the *EC* values for HM Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn reached values lower than 1.0 mg/kg DM, thus a moderate degree of accumulation. Fe reached *EC* = 0.07596 mg/kg DM, i.e. *EC* < 0.1, thus a low level of accumulation. In addition, Cd reached the *EC* figure of 4.75 mg/kg DM, thus *EC* > 1.0, high level of accumulation.

Sample 4 showed in majority of heavy metals (Co, Cu, Mn, Ni, Pb and Zn) *EC* values lower than 1.0 mg/kg DM, i.e. a moderate degree of accumulation. The *EC* values in Cr (0.0593 mg/kg DM) and Fe (0.0312 mg/kg DM) showed figures lower than 0.1 mg/kg DM, a low degree of accumulation. Similarly, as in samples 1, 2 and 3 the Cd element reached higher *EC* figures than 1.0, for sample 4 the value of the *EC* amounted to 20.32 mg/kg DM, thus extremely high degree of accumulation.

This figure was the highest of all 8 observed sampling points. In sample 5 the Cr, Fe, Mn, Ni showed the *EC* values <0.1 mg/kg DM, thus a low degree of accumulation. As for elements Co, Cu, Pb, Zn the figures amounted to *EC* < 1.0, a moderate degree of accumulation and in the Cd element (4.3684 mg/kg DM) the *EC* >1.0 mg/kg DM, therefore a high degree of accumulation.

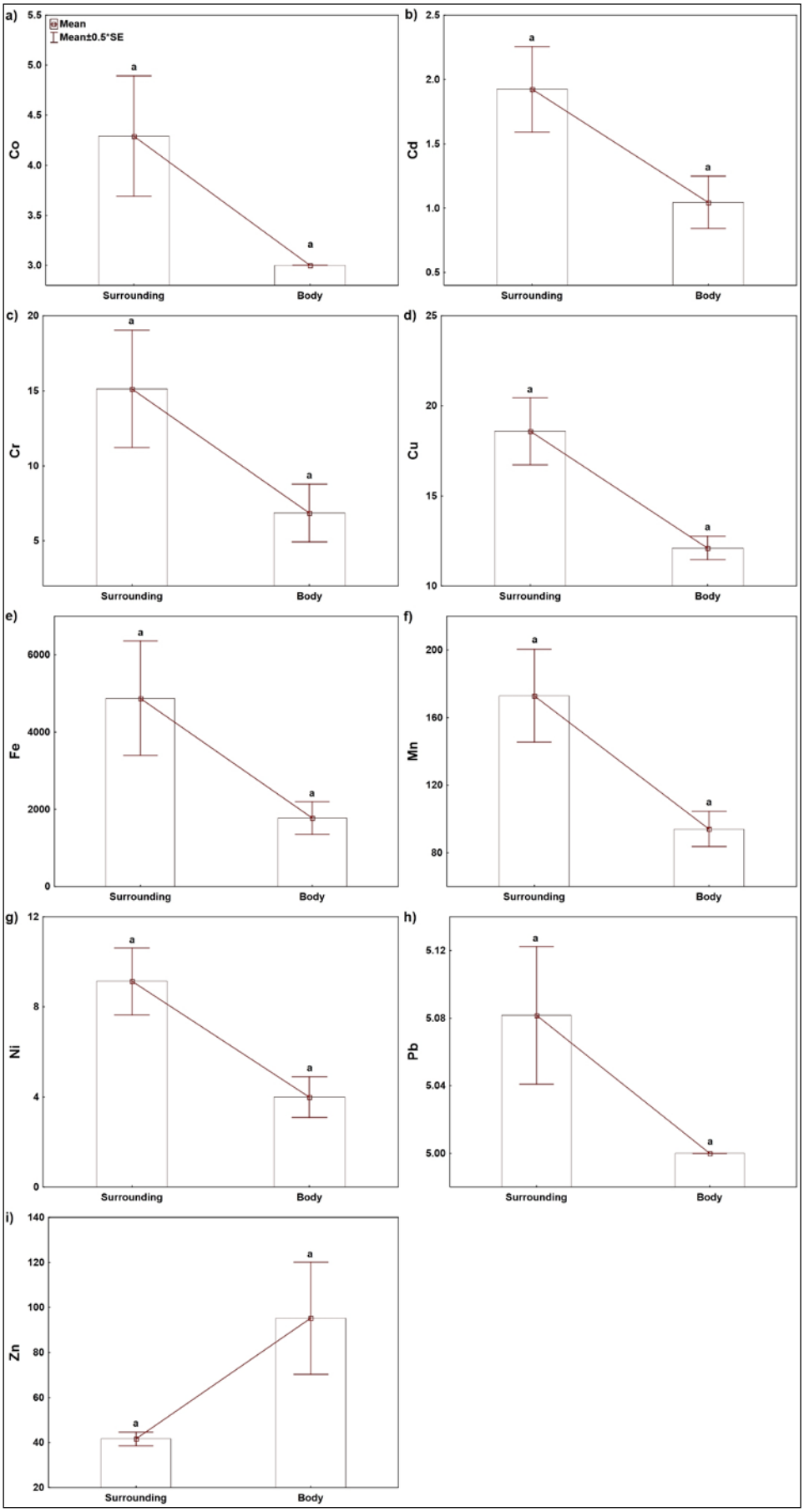

Fig. 7. The mean concentration of HM in plants

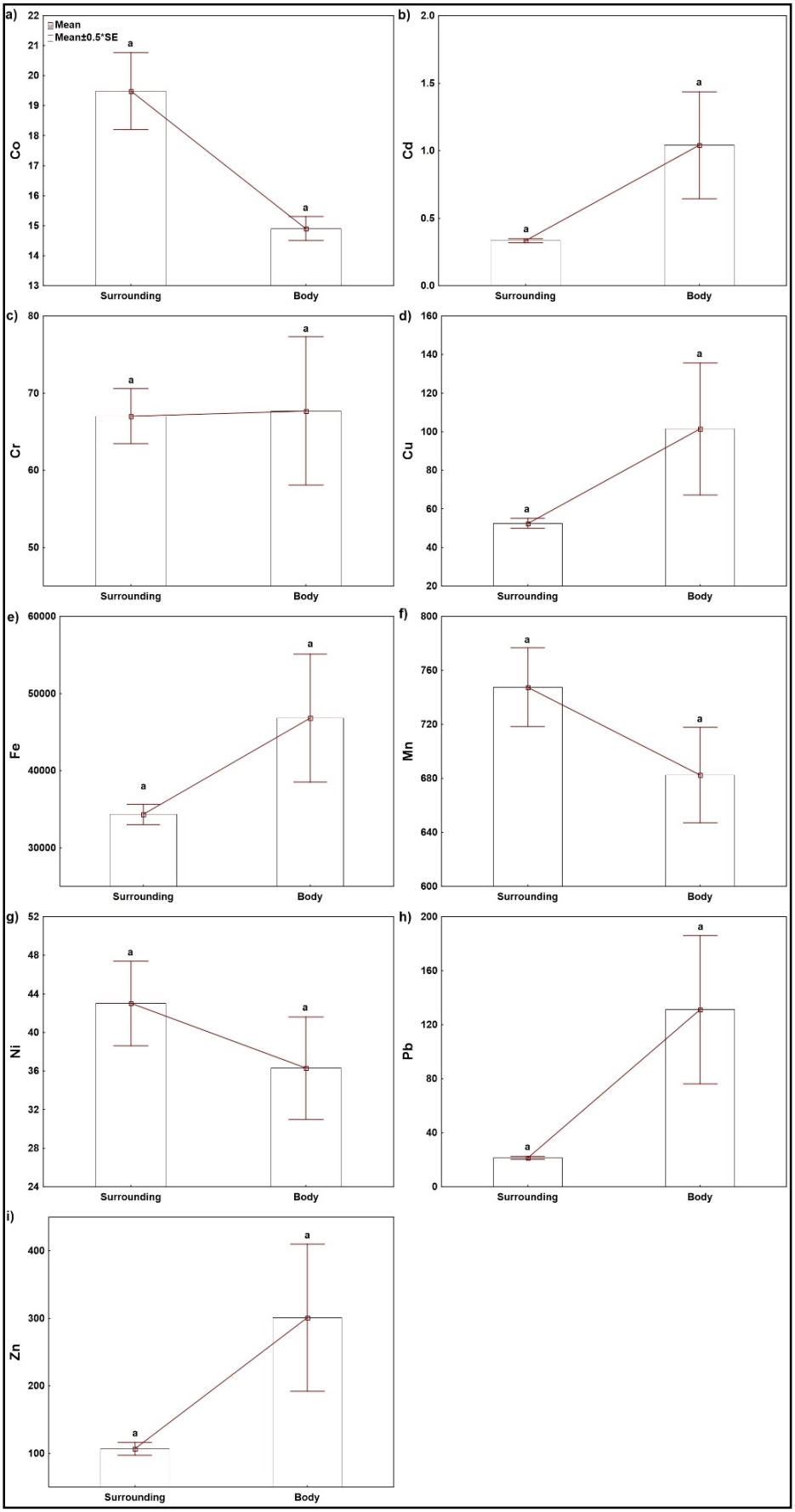

Fig. 8. The mean concentration of HM in soil

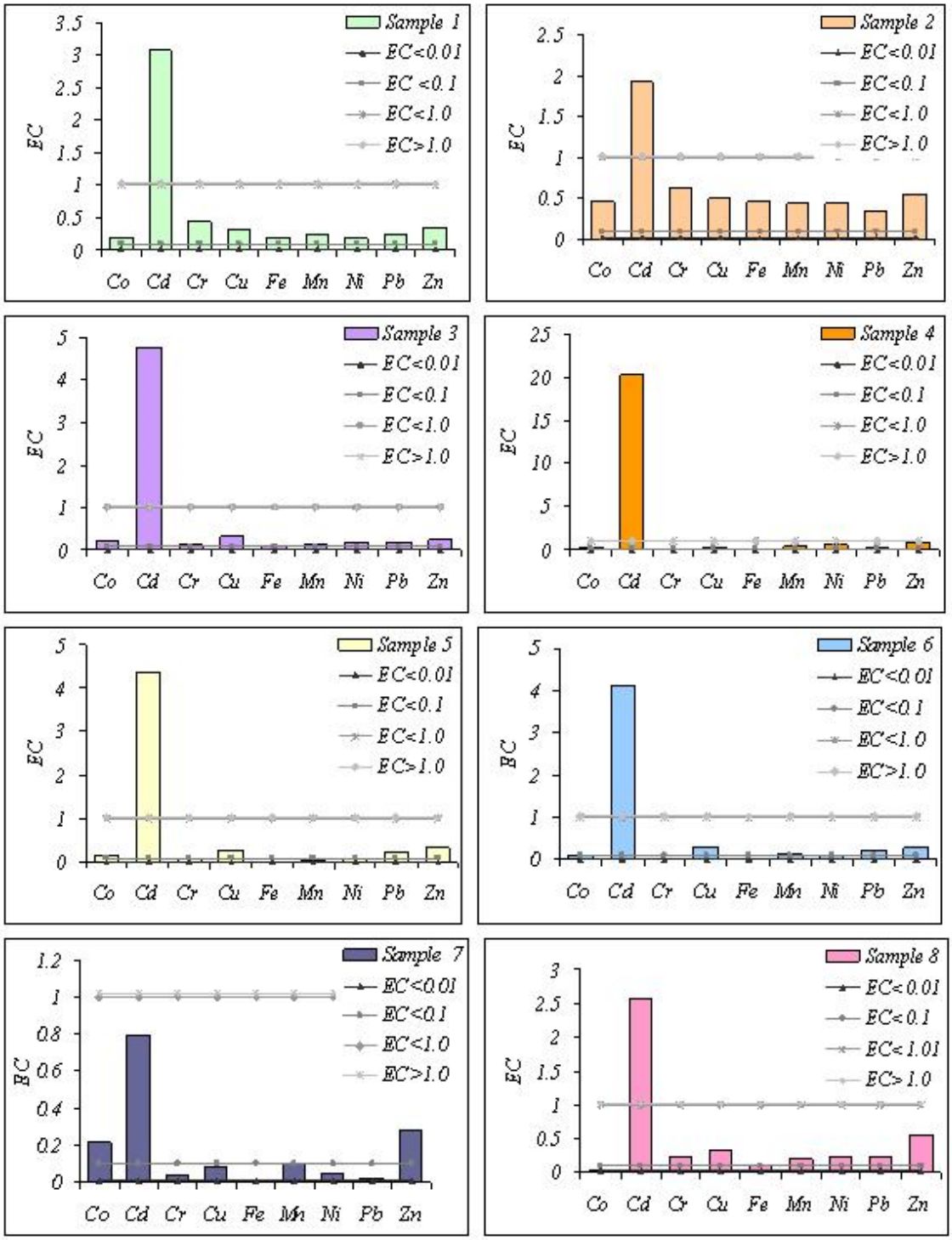

Fig. 9. *EC* (mg/kg DM) samples 1-8

As for sample 6 the *EC* values for the elements Cr, Fe, Ni showed figures lower than 0.1 mg/kg DM, i.e. low degree of accumulation. With regard to the elements Co, Cu, Pb and Zn the *EC* values were < 0.1 mg/kg DM, therefore a moderate degree of accumulation. Similarly, to all previous samples (1-5) also in sample 6 the Cd element (4.107 mg/kg DM) reached the highest *EC* value, where the *EC* > 1.0 mg/kg DM, thus a high degree of accumulation.

As for sample 6 the *EC* values for the elements Cr, Fe, Ni showed figures lower than 0.1 mg/kg DM, i.e. low degree of accumulation. With regard to the elements Co, Cu, Pb, Mn and Zn the *EC* values were < 1.0 mg/kg DM, therefore a moderate degree of accumulation. Similarly, to all previous samples (1,2,3,4,5) also in sample 6 the Cd element (4.107 mg/kg DM) reached the highest *EC* value, where the *EC* > 1.0 mg/kg DM, thus a high degree of accumulation. In sample 7 the Cr, Cu, Fe, Mn, Ni a Pb showed *EC* values lower than 0.1 mg/kg DM, a low degree of accumulation. *EC* values of the element Co (0.2127 mg/kg DM), Cd (0.7923 mg/kg DM) and Zn

(0.2793 mg/kg DM) reached *EC* values lower than 1.0 mg/kg DM, i.e. a moderate degree of accumulation. In contrast to previous samples, in this sample the element Cd did not exceed *EC* >1.0 (a high degree of accumulation), despite compared to other elements it reached the highest value of *EC*. In sample 8 the *EC* values for elements of Cr, Cu, Mn, Ni, Pb and Zn reached values lower than 1.0 mg/kg DM, therefore a moderate degree of accumulation; as for the elements Co and Fe, the value of *EC* amounted to *EC* < 0.1 mg/kg DM, a low degree of accumulation. In addition, in sample 8 the Cd reached the value of *EC* = 2.56 mg/kg DM, i.e. *EC* > 1.0, thus a high level of accumulation.

4. Discussion

Environmental pollution with HM poses a grave problem to the contemporary world. The ions of many HM, such as Cu, Zn, Mn, Fe, and Ni are important microelements in the mineral nutrition of plants, but at high levels and jointly with other metals, such as Cd and Pb, could become extremely toxic. Owing to their ability to effectively capture and accumulate chemical substances from the environment, the plants are widely used as passive biomonitors and for phytoremediation (Radziemska et al., 2017).

According to the results, concentrations of HM in plants, taken from the surrounding of the landfill, are slightly higher when compared to the plant samples from the body of the landfill. The only exception is Zn, where the average concentration of samples from the surrounding is 66 % lower. The higher concentrations of Cd in the samples from the landfill surrounding could be related to the agricultural utilizing of the immediate land. The *T. vulgare* is a representative of perennial plants and is exposed to the impacts of environment for a long time. Application of mineral fertilizers can significantly decrease the pH value and contribute to increase the Cd solubilization (Lambert et al., 2007). Application of phosphorus containing fertilizers can also significantly increase the concentrations of Cd in the soil (Lambert et al., 2007; Schipper et al., 2011; Wu et al., 2012). On the other hand, results of Hejcman et al., (2013), who analyzed the effect of longtime application of mineral and organic fertilizers on the concentration of HM in the arable layer do not support this idea. The concentration of Cd in the samples from the bottom border of arable field contained approximately 5 mg Cd kg^{-1}, the highest concentration among all plant samples. The *T. vulgare* is concerned as a good bioindicator as the even small amounts of Cd in the environment cause significant uptake in the plant (Jasion et al., 2013; Vaverková and Adamcová, 2014).

According to edict Nr 13/1994, estimating the soil HM limits, the mean concentrations of Cd, Cu, Pb and Zn from the body of the landfill slightly exceeded the limits. As it was determined only two spots from the landfill body, the standard error values ranged significantly, showing high fluctuation between the samples. The high HM concentrations are from the uncovered part of the landfill, showing high intoxication of the locality. The possibility of growth of *T. vulgare* on such positions supports the results of Jasion et al., 2013, who published the idea that *T. vulgare* has possibility to accumulate, as a plant strategy, metals in the roots than in stems, leaves and flowers to protect the photosynthetic tissues, giving the *T vulgare* advantages in comparison with other plants and supports the possibility to use this plant as bioindicator (Adamcová et al., 2017).

In this study *T. vulgare* was selected because it is a common and widespread plant with a high degree of adaptability and grows spontaneously in Štěpánovice landfill. *T. vulgare's* wide distribution indicates high ecological plasticity in different environmental conditions. Therefore, it was of interest to investigate the bioaccumulation abilities of this species. In addition, monitoring of metal concentrations is necessary in this type of environment. *T. vulgare* may be considered a good bioindicator. *EC* indicates phytoremediation potential of *T. vulgare.* This plant was selected for further research that will focus on possibilities of using *T. vulgare* for phytoremediation of the landfill site.

4. Conclusions

The examined plant and soil samples meet the stated requirements. The highest values in plant samples reached Fe, Mn and Zn. The highest concentrations of HM were observed in plant samples 4, 2 and 1, i.e. plants collected in the vicinity of the landfill. The highest values in soil samples reached Fe, Mn and Zn. The highest concentrations of HM were observed in soil samples 7, 2 and 5. The highest *EC* was observed for Cd in all sampling points. In contrast, the lowest concentration of all the examined heavy metals was determined for Cd in plant and soil samples.

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References

Abu-Darwish M.S., Abu-Dieyeh Z.H.M., (2009), Essential oil content and heavy metals composition of Thymus vulgaris cultivated in various climatic regions of Jordan, *International Journal of Agriculture and Biology*, **11**, 59-63.

Adamcova D., Radziemska M., Ridoskova A., Barton S., Pelcova P., Elbl J., Kynicky J., Brtnicky M., Vaverkova M.D., (2017), Environmental assessment of the effects of a municipal landfill on the content and distribution of heavy metals in *Tanacetum vulgare* L., *Chemosphere*, **185**, 1011-1018.

Chao W., Xiao-chen L., Li-min Z., Pei-fang W., Zhi-yong G., (2007), Pb, Cu, Zn and Ni concentrations in vegetables in relation to their extractable fractions in

soils in suburban areas of Nanjing, China, *Polish Journal of Environmental Studies*, **2**, 199-207.

Connolly J.H., Jellison J., (1997), Two way translocation of cations by the brown rot fungus Gloeophyllum trabeum, *International Biodeterioration & Biodegradation*, **39**, 181-188.

Elbl J., Polšek L., Kintl A., (2014), The effect of increased doses of compost on leaching of mineral nitrogen from arable land, *Polish Journal of Environmental Studies*, **23**, 697-703.

Fellner J., Brunner P.H., (2010), Modeling of leachate generation from MSW landfills by a 2-dimensional 2-domain approach, *Waste Management*, **30**, 2084-2095.

Grigalavičienė I., Rutkovienė V., Marozas V., (2005), The Accumulation of heavy metals Pb, Cu and Cd at roadside forest soil, *Polish Journal of Environmental Studies*, **14**, 109-115.

Grzesik K., Malinowski M., (2017), Life Cycle Assessment of Mechanical-Biological Treatment of Mixed Municipal Waste, *Environmental Engineering Science*, **34**, 207-220.

Hejcman M., Berková M., Kunzová E., (2013), Effect of long-term fertilizer application on yield and concentrations of elements (N, P, K, Ca, Mg, As, Cd, Cu, Cr, Fe, Mn, Ni, Pb, Zn) in grain of spring barley, *Plant, Soil and Environment*, **59**, 329-334.

Jasion M., Samecka-Cymerman A., Kolon K., Kempers A.J., (2013.), Tanacetum vulgare as a bioindicator of trace-metal contamination: a study of a naturally colonized open-pit lignite mine, *Archives of Environmental Contamination and Toxicology*, **65**, 442-448.

Jones P.T., Geysen D., Tielemand Y., Van Passel S., Pontikes Y., Blanpain B., Quaghebeur M., Hoekstra N., (2013), Enhanced Landfill Mining in view of multiple resource recovery: a critical review, *Journal of Cleaner Production*, **55**, 45-55.

Lambert R., Grant C., Sauvé S., (2007), Cadmium and zinc in soil solution extracts following the application of phosphate fertilizers, *Science of the Total Environment*, **378**, 293-305.

Kabata-Pendias A., Pendias H., (1999), Biogeochemistry of trace elements (in Polish), *Wyd. Nauk. PWN, Warszawa*, 74-102.

Kachenko A.G., Singh B., (2006), Heavy metals contamination in vegetables grown in urban and metal smelter contaminated sites in Australia, *Water, Air, and Soil Pollution*, **169**, 101-123.

Koda E., Pachuta K., Osinski P., (2013), Potential of Plant Applications in the Initial Stage of the Landfill Reclamation Process, *Polish Journal of Environmental Studies*, **22**, 1731-1739.

Koda E., Sieczka A., Osinski P., (2016), Ammonium concentration and migration in groundwater in the vicinity of waste management site located in the neighborhood of protected areas of Warsaw, Poland, *Sustainability*, **8**, 1253.

Koda E., Osiński P., (2017), Bentonite cut-off walls: solution for landfill remedial works, *Environmental Geotechnics*, **4**, 223-232.

Malayeri B.E., Chehregani A., Yousefi N., Lorestani B., (2008), Identification of the hyper accumulator plants in copper and iron mine in Iran, *Pakistan Journal of Biological Science*, **3**, 490-492.

Mazzeo R., Nannoni F., Protano G., Manti A., Santolini R., (2013), Integrated approach for the analysis of ecosystems at risk: a case study in a waste landfill, *Environmental Engineering and Management Journal*, **12**, 165-168.

Ozkaya B., Demir A., Sinan Bilgili M., (2006), Mathematical simulation and long-term monitoring of leachate components from two different landfill cells, *Journal of Hazardous Materials*, **A135**, 32-39.

Pederson G.A., Geoffrey E.B., Fairbrother T.E., (2002), Nutrient uptake in plant parts of sixteen forages fertilized with polutry litter: nitrogen, phosphorus, potassium, copper and zinc, *Agronomy Journal*, **94**, 895-904.

Radziemska M., Gusiatin Z.M., Bilgin A., (2017), Potential of using immobilizing agents in aided phytostabilization on simulated contamination of soil with lead, *Ecological Engineering*, **102**, 490-500.

Schipper L.A., Sparling G.P., Fisk L.M., Dodd M.B., Power I.L., Littler R.A., (2011), Rates of accumulation of cadmium and uranium in a New Zealand hill farm soil as a result of long-term use of phosphate fertilizer, *Agriculture, Ecosystems & Environment*, **144**, 95-101.

Stevovi S., Surcinski V., Calic-Dragosavac M., Calic-Dragosavac D., (2010), Environmental impact of site location on macro- and microelements in Tansy, *African Journal of Biotechnology*, **16**, 2408-2412.

Stevovic S., Mikovilovic S.V., Calic-Dragosavac D., (2009), Environmental adaptibility of tansy (*Tanacetum vulgare* L.), *African Journal of Biotechnology*, **8**, 6290-6294.

Turan N.G., Baki O.G., Ergun O.N., (2016), Municipal solid waste characteristics and management in Sinop, Turkey, *Environmental Engineering and Management Journal*, **15**, 13-18.

Vaverková M.D., Adamcová D., (2014), Heavy metals uptake by select plant species in the landfill area of Štěpánovice, Czech Republic, *Polish Journal of Environmental Studies*, **23**, 2265-2269.

Vaverková M.D., Adamcová D., (2018), Case study of landfill reclamation at Czech landfill site, *Environmental Engineering and Management Journal*, **17**, 641-648.

Vaverková M.D., Radziemska M., Bartoň S., Koda E., (2018), The use of vegetation as a natural strategy for landfill restoration, *Land Degradation and Development*, **29**, 3674-3680.

Wu, L. Tan Ch., Liu L., Zhu P., Peng Ch., Luo Y., Christie P., (2012), Cadmium bioavailability in surface soils receiving long-term applications of inorganic fertilizers and pig manure, *Geoderma*, **173-174**, 224-230.

Wyszkowski M., Radziemska M., (2009), The effect of chromium content in soil on the concentration of some mineral elements in plants, *Fresenius Environmental Bulletin*, **18**, 1039-1045.