Pol. J. Environ. Stud. Vol. 23, No. 2 (2014), 501-509

Original Research

Can Vegetation Indicate a Municipal Solid Waste Landfill's Impact on the Environment?

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Received: 9 July 2013
Accepted: 10 December 2013

Abstract

Our paper focused on the determination of heavy metals and nitrates in tomatoes (*Lycopersicon esculentum*). Four samples of tomatoes were analyzed by an accredited testing laboratory. The concentrations of heavy metals and nitrates in tomatoes spontaneously occurring on the landfill body meet the limits provided by law. Tomatoes from a chain store and private grower were used as standards. The conducted research complemented classic landfill monitoring (17 years) and long-term biomonitoring (6 years) of the landfill body and the nearest surroundings. Neither the concentrations of heavy metals in the tomatoes nor the concentrations of heavy metals in surface water, ground water, and leachate exceeded the limits stipulated by law. During the period of monitoring, no significant impact of the landfill on the environment was detected.

Keywords: landfill sites, vegetation, heavy metal content, nitrates content, Czech Republic

Introduction

Although reduction, recycling, and reuse of municipal refuse are preferred practices, solid waste disposal in landfills is still a common occurrence throughout the world [1]. In fact, about 70% of municipal solid wastes (MSW) currently go into landfills in Czech Republic. Landfilling is usually done by the containment of different types of inert waste, i.e. by sealing the base and sides, and by capping sites with impermeable materials topped by soil to a depth of at least 1 m, all combined with the installation of leachate and gas management systems [2]. Restoration of landfill caps is generally considered problematic because of poor soil structure (most often from imported soils from various sources), coarse substrate, and a high concentration of landfill gas [2]. Little is known about the plant communities of these sites or of the role of restored landfill caps within the broader biodiversity conservation framework [2].

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In previous work [3, 4] the evidence obtained over the past 6 years of the impact of MSW (landfill Štěpánovice) on the close vicinity was examined. Based on them, it was concluded that an accurate ecotoxicological diagnosis cannot be solely based on the factors most closely related to the plant populations and communities at the sites under the impact of a landfill. Therefore, the chemical analysis of vegetation with a focus on tomatoes (*Lycopersicon esculentum*) growing on the landfill was performed. Only a few similar ecotoxicological studies on MSW landfills appear to have been conducted to date but no with tomatoes [5-9].

Nature of the Problem

The presence of metals in soils is related to 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 [10, 11]. However, anthropogenic inputs associated with agricultural practices, mineral exploration, industrial processes, and solid waste management are important contributors to heavy metal contamination of natural ecosystems [12-14].

Most vegetable species growing in metal-polluted soils are unable to avoid the absorption of these elements [15]. Accumulation of heavy metals and metalloids in agricultural soils is a subject of increasing concern due to food safety issues and potential health risks, as well as detrimental effects on soil ecosystems [16].

Toxic effects of metals have been widely described. Elements such as arsenic, cadmium, lead, mercury, and nickel, etc., have a wide spectrum of toxicity that includes neurotoxic, hepatotoxic, nephrotoxic, teratogenic, and mutagenic effects, among others [17-21]. Moreover, elements such as cadmium, chromium, and arsenic also are considered carcinogenic [22].

Experimental Procedures

Site Description

The study site is located 1 km north of Štěpánovice commune and 1 km south of Dehtín commune. GPS coordinates of the test point are 49º26'15.934"N, 13º16'55.352"E (Fig. 1). In this area, mean annual precipitation is 582 mm and mean annual temperature is 8.0ºC. The landfill has been operating since summer 1996. It is situated in the northern part of a widely opened W-E valley. The bottom part of this area is restricted with a nameless stream being the right tributary of the Úhlava River. The upper part of the area is covered with woodland vegetation predominated by *Pinus sylvestris*. The southern slope is used for agriculture. The landfill is located on the north slope from the valley axis. In the past, the landfill area was used as a meadow [3, 4]. In terms of maintenance, the landfill is classified in the S-category (other waste, sub-category S-OO_3). The landfill has a total authorized volume of about 569,000 m^3; at the moment, it is being used to dispose of mixed municipal waste. The landfill (Fig. 4) is formed by three sub-landfills: landfill A (closed in 2003, area 8,750 m^2); landfill B (working from 2003, area 26,000 m^2); and landfill C (which will work after closing part B). The total volume of both (A, B) parts of the landfill is 289,000 m^3. Planned service life of the facility is up to year 2018. Waste generation and composition in 2004-11 is presented in Tables 1, 2, and Fig. 2 [23].

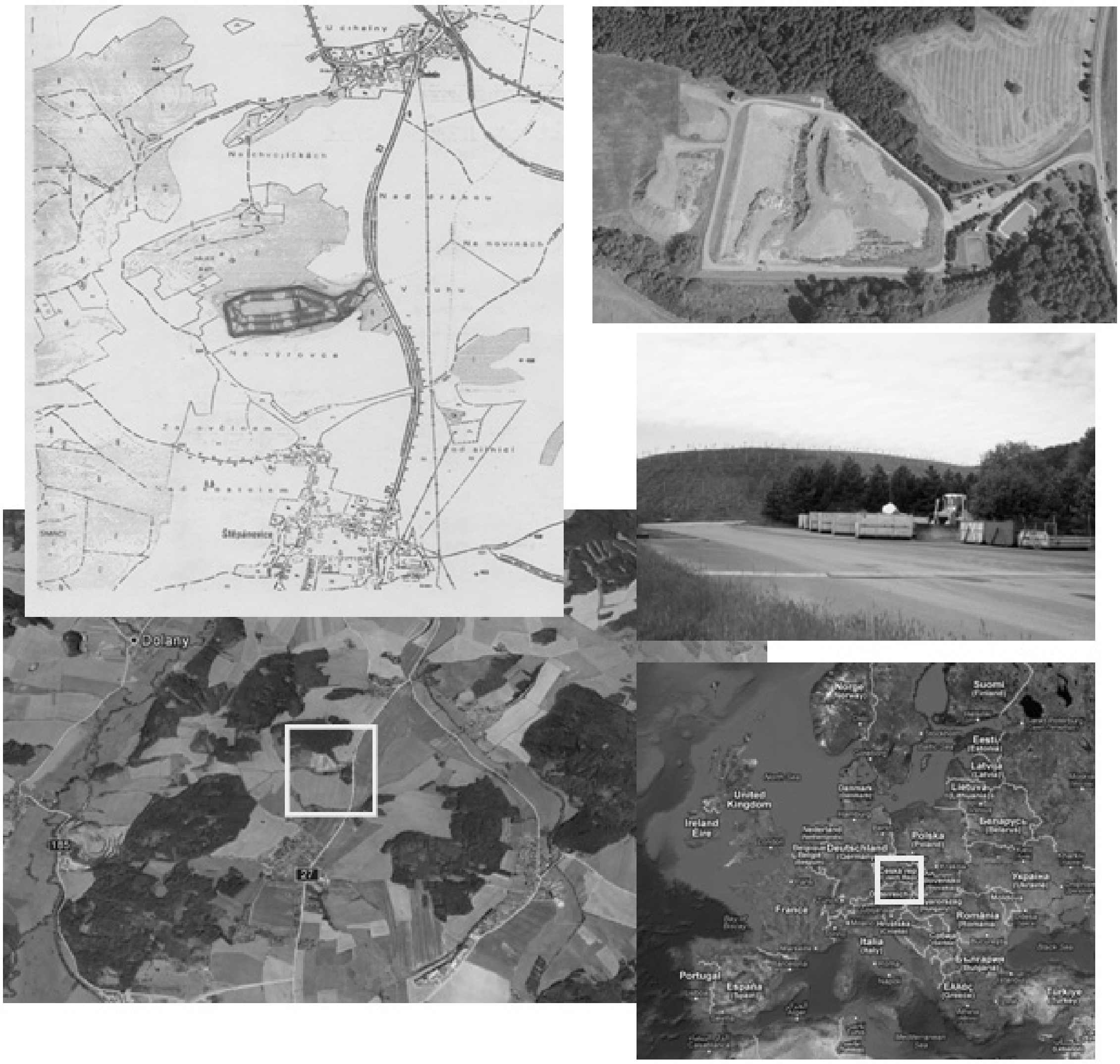


Fig. 1. General site location [23].

Table 1. Waste quantity landfilled in 2004-11 [23].

Year	Waste [Mg]	Biodegradable waste [Mg]	Total [Mg]
2004	16,463	3,686	20,149
2005	16,320	3,647	19,967
2006	16,189	3,729	19,918
2007	16,180	4,484	20,664
2008	26,433	5,391	31,824
2009	16,980	4,971	21,951
2010	16,891	4,320	21,211
2011	7,798	1,663	9,461

The total amount (Mg) of each type of waste placed in the landfill MSW Štěpánovice in 2004-11 is shown in Fig. 2. The greatest amount of waste placed in the landfill in the reporting period represents mixed municipal waste (55,780 Mg), followed by bulky waste (32,831 Mg) and bricks (30,014 Mg) [23].

Monitoring of Landfill Leachate, Surface and Groundwater Quality

The landfill is subject to monitoring of surface water, ground water, and leachate at regular intervals. Samples of ground water and surface water are taken from five sampling points marked as follows (designation – characterization): A – old borehole (below the landfill), B – new borehole (above the landfill), C – bedrock, D – brook below the landfill (less than 2 m from the former place), and E – brook above the landfill. Samples of leachate (F) are taken from the detention receiver of leachate. Thus, there are altogether six sampling points: leachate water (F – Hg, Zn, Ni, Cd, Pb, Cr^{6+} [$\mu g/dm^3$], groundwater (A, B, C – Hg, Zn, Ni, Cd, Pb, Cr^{6+} [$\mu g/dm^3$], and surface water (D, E – Hg, Zn, Ni, Cd, Pb, Cr^{6+} [$\mu g/dm^3$]).

The obtained values were assessed pursuant to the criteria set forth in the Methodological Guide of the Ministry of the Environment of the Czech Republic – "Soil and Groundwater Contamination Criteria" (1996), according to the Czech National Standard (ČSN 75 7221 "Classification of Surface Water Quality)," and ČSN 75 7111 "Drinking water."

Table 2. Waste composition in 2004-11 [23].

Waste type	2004	2005	2006	2007	2008	2009	2010	2011
	Mg	Mg	Mg	Mg	Mg	Mg	Mg	Mg
Waste tanned leather	6.34	4.65	4.34	2.18	2.26	1.45	1.87	1.23
Wastes from processed textile fibres	104.49	63.14	140.02	26.88	22.89	39.52	25.36	22.19
Coal fly ash			2.21		13.27		64.94	71.69
Plastic packaging	62.83	69.94	79.07	67.88	72.46	72.38	80.24	40.82
Mixed packaging	30.39			43.84	53.39	56.3	224.35	169.04
Concrete	189.05	280.07	250.96	328.83	234.61	256.01	246.99	347.78
Bricks	3,329.97	3867.8	4,004.69	3,841.42	4,763.29	3,685.69	4,651.02	1,870.39
Tiles and ceramics	26.63	137.96	36.38	127.07	41.14	63.68	31.36	17.8
Soil, stones, and dredging spoil							1,562.96	1,162.98
Insulation materials	18.4	2.99	3.86	69.84	19.74			
Gypsum	15.72	3.55	22.54	1,255.44	6,935.3	990.68	1,185.74	614.53
Mixed construction wastes	779.36	985.04	1,577.7			39.59	41.39	20.79
Screenings		4.94	5.31	10.78	2.36	125.77	113.77	34.31
Waste from desanding	143.72	117.94	95.42	101.6	113.98			
Biodegradable waste			0.73	1	5.81	7.94	1.31	
Soil and stones	2,278.05	2,216.57	2,648.82	2,138.18	6,163.59	3,692.65	561.94	
Mixed municipal waste	7,308.01	7,360.08	7,435.23	7,789.54	7,518.88	7593.9	7,623.3	3,150.79
Waste from markets	193.78	168.09	153.75	120.7	151.64	165.28	136.17	49.36
Street-cleaning residues	400.5	317.8	183.71	353.02	461.46	332.85	430.4	268.58
Bulky waste	5,107.87	4,285.12	3,250.43	4,357.47	5,234.53	4,797.84	4,183.22	1,614.3
Total	19,995.11	19,885.68	19,895.17	20,635.67	31,810.60	21,921.53	21,166.33	9,456.58

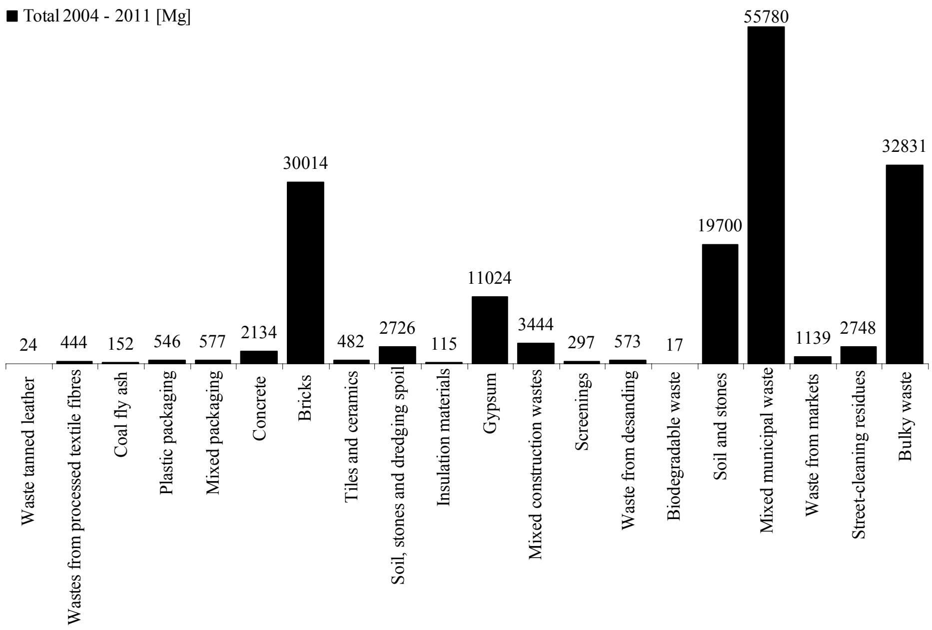


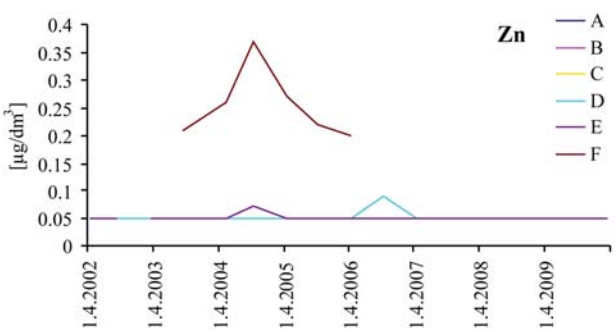
Fig. 2. Total quantity of individual waste in 2004-11 [23].

All samples are monitored for parameters required by valid legislation as well as for the occurrence of heavy metals: Zn, Cr^{6+}, Hg, Ni, Cd, and Pb. Figs. 3-8 illustrate the courses of heavy metal concentrations (mg/dm^3) from all six sampling points in the period 2002-10.

The measured data show that the concentrations of heavy metals meet the limits provided by law. Under the current landfill operation mode, the results of measurements do not indicate any negative impact on the quality of surface water, ground water, or seepage water.

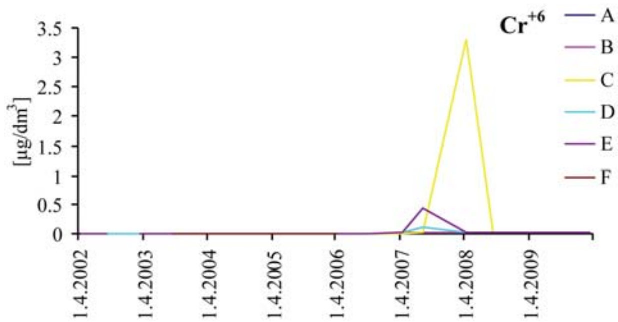
Field Investigation – Site Selection

Plant determination and sampling were made at the mid-growing period (25.09.2012). Two sites were chosen on the north east-facing slope of the landfill (Fig. 9). Sub-landfill B has rich vegetation growth. Sub-landfills A and B have low landfill gas content.



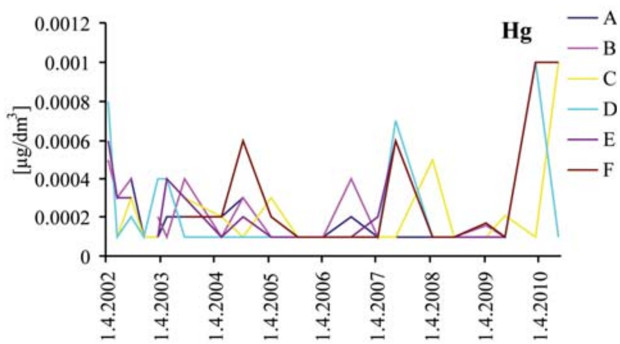
Zn	Limit [μg/dm^3]
Drinking water	5000
Groundwater	150
Surface water	15

Fig. 3. Concentrations of heavy metal (Zn) from the sampling points for the period 2002-10.



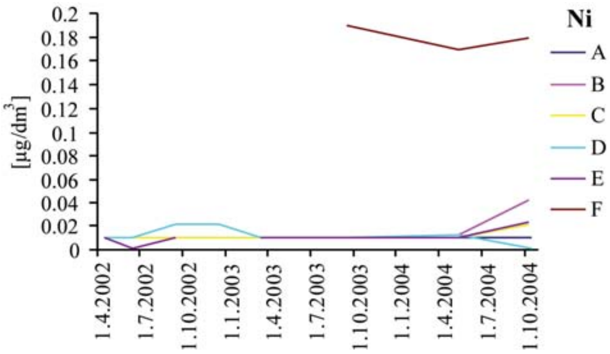
Cr^{+6}	Limit [μg/dm^3]
Drinking water	-
Groundwater	1
Surface water	5

Fig. 4. Concentrations of heavy metal (Cr^{+6}) from the sampling points for the period 2002-10.



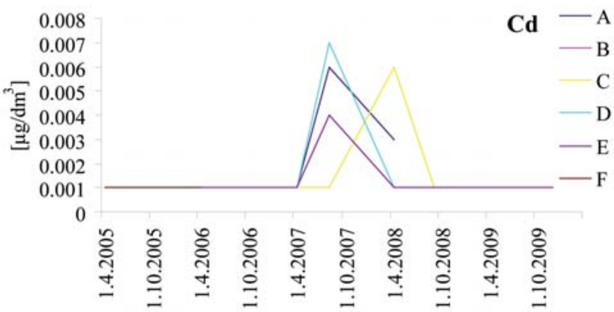
Hg	Limit [μg/dm^3]
Drinking water	1
Groundwater	0.1
Surface water	0.05

Fig. 5. Concentrations of heavy metal (Hg) from the sampling points for the period 2002-10.



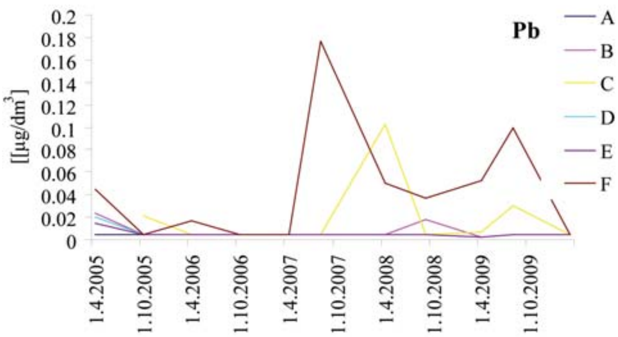
Ni	Limit [μg/dm^3]
Drinking water	-
Groundwater	20
Surface water	5

Fig. 6. Concentrations of heavy metal (Ni) from the sampling points for the period 2002-04.



Cd	Limit [μg/dm^3]
Drinking water	0.005
Groundwater	1.5
Surface water	0.1

Fig. 7. Concentrations of heavy metal (Cd) from the sampling points for the period 2005-10.



Pb	Limit [μg/dm^3]
Drinking water	0.05
Groundwater	20
Surface water	3

Fig. 8. Concentrations of heavy metal (Pb) from the sampling points for the period 2005-10.

Table 3. Information about the samples.

Sample designation	Sampling point	Country of origin
1	Landfill MSW Štěpánovice SW	Czech Republic
2	Landfill MSW Štěpánovice NE	Czech Republic
3	La Palma (chain store)	Spain
4	Vysočina Region (private grower)	Czech Republic

Samples of tomatoes (fruits) taken from two select sites of the landfill body (Fig. 9) were placed into 2 separate carrying boxes made of perforated paper. The boxes were labelled for easy identification and brought to the laboratory of the Department of Applied and Landscape Ecology, Mendel University in Brno, where they were photographed for documentation and prepared for further research.

In addition to the tomato samples taken from the landfill body, there were other two samples that were subject to our research: tomatoes (fruits) bought in a chain store and another sample of tomatoes was provided from a private grower. The samples were transported in perforated paper boxes again and properly labeled. Detailed identification of the examined samples is presented in Table 3.

Prior to subsequent research, all samples were photographed for documentation and labelled (Fig. 10).

The examined samples were brought to the accredited testing laboratory LABTECH s.r.o. Polní, Brno for analyses. The materials were analyzed for the content of heavy metals (arsenic, cadmium, chromium, copper, molybdenum, nickel, lead, zinc, mercury) and nitrates. For the determination of the contents of heavy metals, the samples were mineralized by microwave digestion with HNO_3 and H_2O_2.

Results and Discussion

The established values of analyzed materials are presented in Tables 4-7. Results for sample No. 1 (labeled in the laboratory as B8469) are presented in Table 4, for sample No. 2 (labeled in the laboratory as B8470) – Table 5, for sample No. 3 (labeled in the laboratory as B8471) – Table 6, and for sample No. 4 (labeled in the laboratory as B8472) – Table 7.

Based on the measured values, the results of all four examined samples were subjected to mutual comparison. Fig. 11 shows the comparison of samples 1, 2, 3, and 4 according to the parameter of heavy metals. All the examined samples meet the requirements stipulated by law (Decree No. 305/2004 Coll., determining types of contaminating and toxic substances and their admissible levels in foodstuffs, Methodological Guidance of the Ministry of Environment of the Czech Republic of 31 July 1996 – The Criteria for Soil and Groundwater Contamination, Czech National Standard ČSN 75 7221 – Classification of Surface Water Quality, Czech National Standard ČSN 75 7111 – Drinking Water). However, differences can be seen in some

Table 4. Results for sample No. 1.

Parameter	Unit	Sample No. B8469	NM	Testing method identification	Accr.
As	mg/kg	0.1		ICP 03P:ČSN ENS ISO 17294	A
Cd	mg/kg	0.01		ICP 03P:ČSN ENS ISO 17294	A
Cr	mg/kg	0.17	20%	ICP 03P:ČSN ENS ISO 17294	A
Cu	mg/kg	1.12	20%	ICP 03P:ČSN ENS ISO 17294	A
Mo	mg/kg	0.1		ICP 03P:ČSN ENS ISO 17294	A
Ni	mg/kg	0.28	20%	ICP 03P:ČSN ENS ISO 17294	A
Pb	mg/kg	0.102	20%	ICP 03P:ČSN ENS ISO 17294	A
Zn	mg/kg	2.51	20%	ICP 04 A:ČSN EN ISO 11885	A
Hg	mg/kg	0.001	20%	AAS 06-07:ČSN 757440	A
Nitrate	mg/kg	20.5		SOPN 19:ČSN EN 12011-2	N

A – Accredited standard operating procedure, N – Non-accredited standard operating procedure, NM – Measurement uncertainty

Table 5. Results for sample No. 2.

Parameter	Unit	Sample No. B8470	NM	Testing method identification	Accr.
As	mg/kg	0.1		ICP 03P:ČSN ENS ISO 17294	A
Cd	mg/kg	0.01		ICP 03P:ČSN ENS ISO 17294	A
Cr	mg/kg	0.1		ICP 03P:ČSN ENS ISO 17294	A
Cu	mg/kg	1.35	20%	ICP 03P:ČSN ENS ISO 17294	A
Mo	mg/kg	0.12	20%	ICP 03P:ČSN ENS ISO 17294	A
Ni	mg/kg	0.1		ICP 03P:ČSN ENS ISO 17294	A
Pb	mg/kg	0.1		ICP 03P:ČSN ENS ISO 17294	A
Zn	mg/kg	2.79	20%	ICP 04 A:ČSN EN ISO 11885	A
Hg	mg/kg	0.001	20%	AAS 06-07:ČSN 757440	A
Nitrate	mg/kg	3.59		SOPN 19:ČSN EN 12011-2	N

A – Accredited standard operating procedure, N – Non-accredited standard operating procedure, NM – Measurement uncertainty

Table 6. Results for sample No. 3.

Parameter	Unit	Sample No. B8471	NM	Testing method identification	Accr.
As	mg/kg	0.1		ICP 03P:ČSN ENS ISO 17294	A
Cd	mg/kg	0.022	20%	ICP 03P:ČSN ENS ISO 17294	A
Cr	mg/kg	0.1		ICP 03P:ČSN ENS ISO 17294	A
Cu	mg/kg	1	20%	ICP 03P:ČSN ENS ISO 17294	A
Mo	mg/kg	0.22	20%	ICP 03P:ČSN ENS ISO 17294	A
Ni	mg/kg	0.27	20%	ICP 03P:ČSN ENS ISO 17294	A
Pb	mg/kg	0.216	20%	ICP 03P:ČSN ENS ISO 17294	A
Zn	mg/kg	2		ICP 04 A:ČSN EN ISO 11885	A
Hg	mg/kg	0.001	20%	AAS 06-07:ČSN 757440	A
Nitrate	mg/kg	24		SOPN 19:ČSN EN 12011-2	N

A – Accredited standard operating procedure, N – Non-accredited standard operating procedure, NM – Measurement uncertainty

Table 7. Results for sample No. 4.

Parameter	Unit	Sample No. B8472	NM	Testing method identification	Accr.
As	mg/kg	0.1		ICP 03P:ČSN ENS ISO 17294	A
Cd	mg/kg	0.015	20%	ICP 03P:ČSN ENS ISO 17294	A
Cr	mg/kg	0.1		ICP 03P:ČSN ENS ISO 17294	A
Cu	mg/kg	0.62	20%	ICP 03P:ČSN ENS ISO 17294	A
Mo	mg/kg	0.1		ICP 03P:ČSN ENS ISO 17294	A
Ni	mg/kg	0.33	20%	ICP 03P:ČSN ENS ISO 17294	A
Pb	mg/kg	0.114	20%	ICP 03P:ČSN ENS ISO 17294	A
Zn	mg/kg	2		ICP 04 A:ČSN EN ISO 11885	A
Hg	mg/kg	0.0001		AAS 06-07:ČSN 757440	A
Nitrate	mg/kg	7.12		SOPN 19:ČSN EN 12011-2	N

A – Accredited standard operating procedure, N – Non-accredited standard operating procedure, NM – Measurement uncertainty

values of the samples. The highest values of Cu and Zn contents were found in sample No. 2 (from the Landfill, NE). The highest Ni content was observed in sample No. 4 (private grower). The highest Mo and Pb contents were recorded in sample No. 3 (chain store) and the highest Cr content was measured in sample No. 1 (from the Landfill, SW). Measured values of the other elements did not show any major differences.

Apart from the parameter of heavy metals, the samples were analyzed for the content of nitrates pursuant to the standard ČSN EN 12011-2. Data provided by the accredited laboratory responsible for the analyses indicate that all the examined samples meet the required parameters. The results are presented in a diagram for the comparison of samples (Fig. 12). The highest contents of nitrates were found in sample No. 3 from the chain store (24 mg/kg), and in Sample No. 1 from the Landfill SW (20.5 mg/kg).

Conclusions

Biological monitoring with the use of bioindicators has been taking place in the surroundings of Štěpánovice landfill since 2007 to the present (still ongoing). Within the monitoring, protected species have been found and identified, e.g. *Epipactis helleborine*, *Juniperus communis*, and *Polygala chamaebuxus*.

Also lichens (e.g. *Cladonia arbuscula*, *Hypogymnia physodes*, and *Xanthoria parietina*) have been recorded. In the rainwater reservoir (Fig. 9) the occurrence of *Triturus vulgaris* was recorded. It is necessary to mention that its occurrence may reflect correct operation of the landfill considering the sensitivity of *Triturus vulgaris* to the environment. This species is legally protected and in accordance with Regulation No. 395/1992 Coll. belongs to a highly endangered species. Its presence in the rainwater reservoir

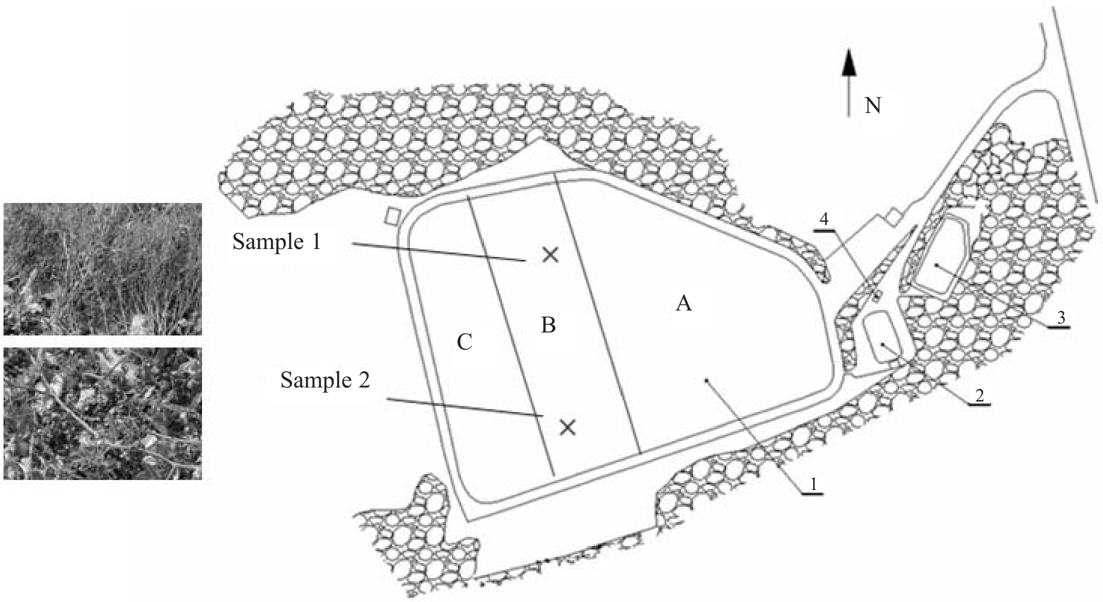


Fig. 9. Map of landfill and sampling points.
1 – landfill, 2 – drained water tank, 3 – rainwater reservoir, 4 – entrance gate

Fig. 10. Sample 1-4.

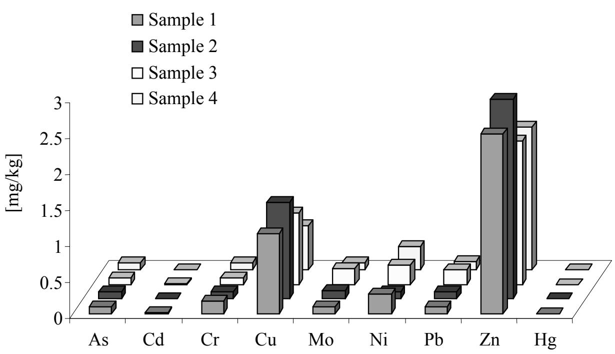


Fig. 11. The contents of heavy metals in the samples (mg/kg).

water proves the clarity of this water and shows that no contamination of water by leachate from the landfill or from the drained water tank takes place.

The present paper investigated the vegetation at Štěpánovice landfill. Our research focused on the determination of heavy metals and nitrates in tomatoes (*Lycopersicon esculentum*) and was conducted in from September to October 2012. Four samples of tomatoes were analyzed by the accredited testing laboratory: one sample from a chain store, one sample from a private grower, and samples taken from two sites of the landfill body. Based on the results of measurements, it was concluded that none of the four samples exceeded the limits established for vegetables. The concentrations of heavy metals and nitrates in tomatoes spontaneously occurring on the landfill body meet the limits provided by law, similar to tomatoes from the chain store and from the private grower. The tomatoes

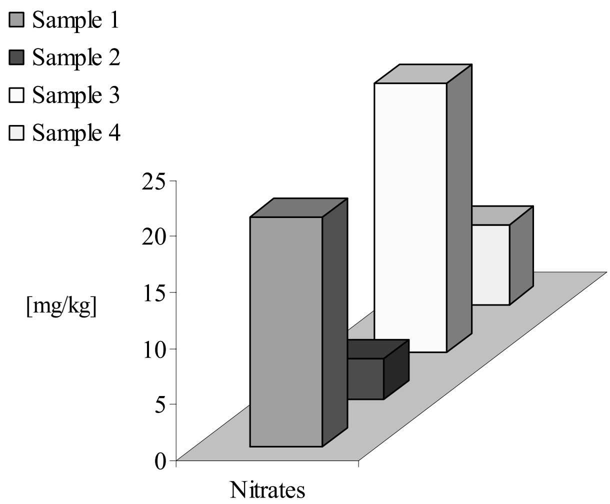


Fig. 12. The content of nitrates in the samples (mg/kg).

from the chain store and private grower were used as standards. Based on results obtained from the comparison, the best of all was sample No. 4. The conducted research complemented the classic landfill monitoring (17 years) and the long-term biomonitoring (6 years) of the landfill body and the nearest surroundings. Neither the concentrations of heavy metals in the tomatoes nor the concentrations of heavy metals in surface water, ground water, and leachate exceeded the limits stipulated by law.

During the period of vegetation biomonitoring, there was no detection of any significant impact of the landfill on the biotic composition of the environment and no symptoms of leaf area chlorosis or necrosis that would have indicated the direct impact of sanitary landfill operation on the location [3, 4]. The landfill is monitored and inspected on a regular basis. In addition to a daily inspection of the landfill, there is also an independent inspection of negative effects on the environment (at least twice a year), especially the monitoring of ground water and leachate from the landfill as well as the analysis of landfill gas formation. The deterioration of measured indicators has not been observed so far [3, 4]. Due to the above, the landfill exploitation (operation) is not a significant negative factor that influences the environment. The performed studies did not confirm the negative impact of landfill on the nearby area.

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