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OCCASIONAL FLOODING IMPACT ON HEAVY METALS CONTENT IN THE SOIL OF POLDER BEŠA

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Three plots in Dry Polder Beša in Slovakia (E) and 3 plots in no flooded area (R) were chosen to assess the Cd, Pb and Ni contamination in the soil by using geo-accumulation index (I_{geo}) and anthropogenic contribution rate (ACR). Heavy metals content was measured at three depths (0–0.2 m, 0.2–0.4 m and 0.4–0.6 m). It was found that the average content of Pb was 1.4 times higher and content of Ni 2.3 times higher at experimental area than at reference area. The average content of Cd were on the same level (E – 0.040 mg/kg, R – 0.041 mg/kg). The variability of heavy metals content in the soil was significantly influenced by soil depth and sampling plot and concentrations significantly correlated with soil organic carbon content (r – in the range of 0.41 to 0.65, $p < 0.05$). Geo-accumulation index indicates that the soils in the all of studied plots were polluted with respect to Ni, while were unpolluted with respect to Cd and Pb. Cd and Pb occurrence in these soils may be associated to the geochemical weathering. The value of the ACR indicate that anthropogenic input of Ni was 1.331 times higher in flooded area than in reference no flooded area. Different soil types can be arranged in descending *Igeo* values for Ni as follows: Luvisols > Regosols > Gleysols > Chernozems. It was found that the content of Ni and Pb exceeded the critical values, in relation to transfer of contaminants from the soil to the plant, only at flooded area.

Key words: heavy metals, pollution level, organic carbon, polder, irregular flooding, profile distribution

Most of the cities and their technological and industrial networks have developed near rivers, which offer favourable conditions for development, such as the availability of fertile lands and fresh water, but the cost for such favourable location is an increased exposure to floods (WMO 2008). Floods may affect critical infrastructure, which can be responsible of soil, surface and groundwater pollution. Among them are waste handling facilities (WFs), landfills and wastewater treatment plants. Some of them (WFs) are susceptible of erosion and leaching behaviour, thus are potential emitters of hazardous substances if flooded (Neuhold & Nachtnebel 2011). Other important sources of pollution are contaminated sites particularly sensitive to inundation because the permanence of floodwater can be responsible of the spread of undesired chemical compounds in the environment. Significant sources of pollution are chemical factories, such as Chemko inc. Strážske was during operation in Slovakia near the Laborec River (Hecl & Danielovič 2008).

Polders are widely known for their advantage in mitigating flood risk by reducing the water levels. Polder ecosystems are distributed worldwide at the lowland areas of aquatic ecosystems, such as Polder Beša in Slovakia at catchment area of Bodrog River. Polder Beša is the largest polder in Central Europe (was built in 1965), with flooded area 1,568 hectares and water capacity is 53 million cubic metre (Kováč *et al.* 2013).

Ecological stability of polders is disturbed by artificial flooding. Irregular flooding of the land causes degradation of biotopes and may also affect soil chemical properties and accumulation of pollutants

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(Beumer *et al*. 2008; Ye *et al*. 2011; Lynch *et al.* 2017).

Rainfed agriculture as the way of intensification constitutes on of the possible answer to farmer´s adaptation to climate variability in the region. Taking into account climate variability, polders represent an interesting agro-economic alternative for farmer, allowing them to develop food security or secure annual revenues (Adoum *et al.* 2017). Control flooding of polders represents one of the way of intensification of agriculture, in this regards polders must be monitored before intensive management application. Therefore, the primary objectives of this study were: (1) to investigate the spatial and profile distribution of heavy metals (including Cd, Pb and Ni) in soils from Dry Polder Beša; (2) to reveal association among selected heavy metals and between heavy metals and soil organic content and soil reaction.

MATERIAL AND METODS

Study area and sampling

The study was conducted at plots situated in Dry Polder Beša and at plots situated close by polder. Dry Polder Beša is located in the southern part of the East Slovak Lowland. Locality belongs to the warm, very dry region with lowland and continental character. Long-term average annual air temperature occur in the interval from 9.0–9.4°C and during vegetation period in the interval from 16.1 to 16.5°C. Long-term annual rainfall is reaching the 571–584 mm and during vegetation period 344–353 mm. The data were observed from hydrometeorological stations in the Vysoka nad Uhom and in the Somotor. At monitored localities the highest sum of rainfall is during summer months (66–82 mm). Due to high air temperatures (18.5 to 20.2°C) during summer months evaporation predominate over the rainfall (Kotorová *et al*. 2008).

Polder Beša was built midst banks of the river Latorica and the river Laborec over their junction. The territory of polder is bounded by the breakwaters of river Laborec and Latorica (from the south and west). From the north and east is bounded by the dykes of division. East dyke is fluently changing into the raised plots, natural borders. The territory of Polder Beša displayed Figure 1. The polder is saturated only exceptionally at special flood situation, only during extraordinary flood. Fifty percent of the area is used for agricultural purposes. The rest area are forests, tufts, shrub woods, uncultivated natural depressions (flooded with water or unflooded), swamps, drainage canal and field paths. Marginal, raised plots with total area 146.1 hectare is arable land and the rest is grassland (638.4 ha).

To determine selected soil parameters six plots were selected (Figure 1). Three of them were placed on the territory of polder, marked as experimental plots (E, total area 73 ha) and others were placed close to the polder, marked as reference plots (R, total area 86 ha). There were analysed three average soil samples at each plot. The experimental and reference plots were permanent grassland, in time of monitoring in 2009 year. The history of plots management is unknown, but known is the fact that Polder Beša was inundated six times by the year 2009, last time in March 2006. In 2006, was filled to 21 percent of the total; in 2000 to 78 percent; in 1999 to 57 percent; in 1980 to 65 percent; in 1979 to 57 percent and in 1974 to 83 percent of total.

Soil samples were collected in spring from three depths: 0–0.2 m, 0.2–0.4 m and 0.4–0.6 m. Collection of soil material was carried out in accordance with standards applicable to the Slovak Republic.

Chemical analysis

The soil samples were analysed to determine content of heavy metals – Cd, Pb, Ni, exchangeable soil reaction in KCl and also to determine contents of soil organic carbon and clay particles. The contents of heavy metals were determined by atomic absorption spectrometry (AAS, Shimadzu AA-660, Japan) in the soil in the extract solution of 1 mol/l ammonium nitrate (ISO 19730 2008) and in the sediment in the extract solution aqua regia (ISO 11466 1995). Exchangeable soil reaction was determined using potentiometric method (ISO 10390 2005; pH meter, Sentron Titan, Netherlands) and soil organic carbon indirectly, by Tjurin´s method (ISO 14235 1998).

Assessment methods

The geo-accumulation index (I_{geo}), also used by Grzebisz *et al.* (2002), Defo *et al.* (2015), Zhang *et al.* (2017) and by others, was selected to determined

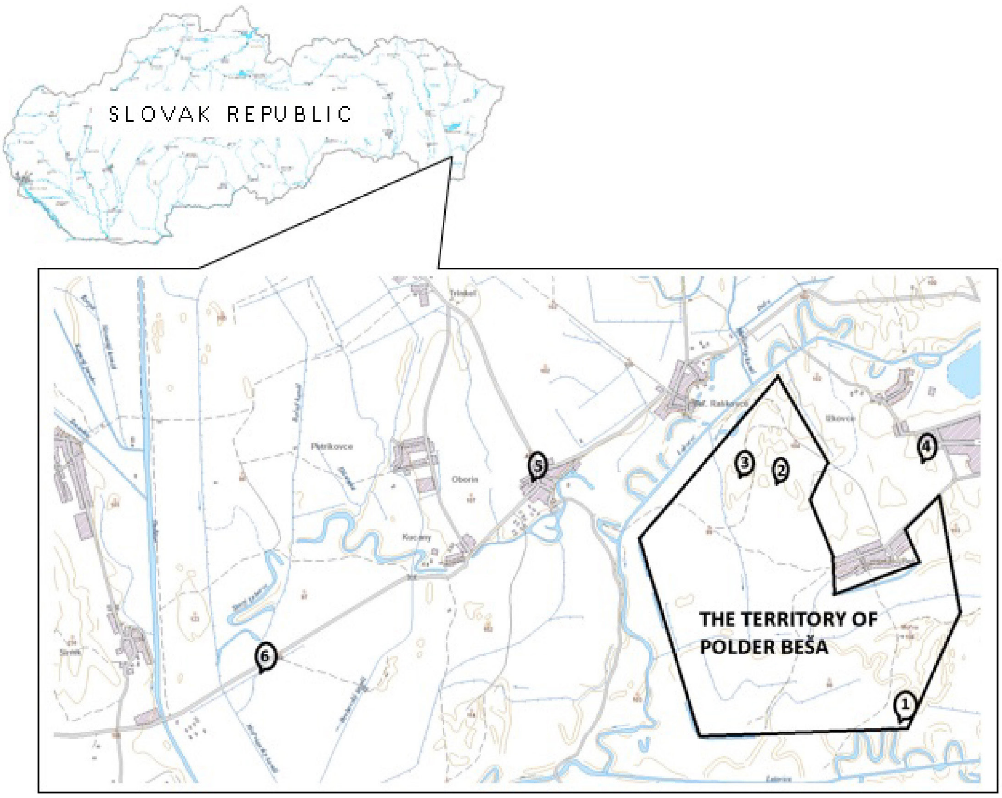

Figure 1. Map of monitored area with marked sampling plots

Points co-ordinates marked in the map:
1. experimental plot 1 (E1) 48° 30' 46" N; 21° 57' 33" E; 2. experimental plot 2 (E2) 48° 32' 36" N; 21° 56' 04" E; 3. experimental plot 3 (E3) 48° 32' 39" N; 21° 55' 30" E; 4. reference plot 1 (R1) 48° 32' 51" N; 21° 57' 47" E; 5. reference plot 2 (R2) 48° 32' 44" N; 21° 52' 59" E; 6. reference plot 3 (R3) 48° 30' 58" N; 21° 49' 46" E

metal pollution in soils. The I_{geo} was introduced by Müller (1986) and is defined as:

$$I_{geo} = log_2(C_n / 1.5 \text{ x } B_n) ,$$

where:
C_n is measured concentration of the element (n) at sampling point; B_n is background concentration value for element content in the soil, 1.5 is the background matrix correction factor due to lithogenic effects. Background values of heavy metals were from the National Agricultural and Food Centre – Soil Science and Conservation Research Institute (Čurlík & Šefčík 1999). In this study background values (specified as total content of heavy metals) must be modified, recalculated to mobile fraction (F1 – water soluble and easily exchangeable metals extracted by 1 M ammonium nitrate). Conversion factors (Makovníková 2000; Tóth 2007) of heavy metals in soils of Slovakia used to calculate mobile fraction from total content are presented in Table 1. In this study the I_{geo} was calculated only for soil depth 0–0.2 m.

Statistical analysis

Contents of Cd, Pb and Ni were evaluated by the multifactor analysis of variance (Anova), with the least significant procedure (*LSD*) and by correlation analysis were evaluated contents of Cd, Pb, Ni, pH and soil organic carbon (Statgraphics Centurion XV, Version 15.2.14).

RESULTS AND DISCUSSION

The content of heavy metals have been studied in the irregularly flooded territory of Dry Polder Beša. Fifty percent of polders area is commonly used as agricultural land. Basic characteristics of sampling plots (soil reaction, organic carbon content and content of clay particles) are shown in Table 2. The experimental plots, according to content of clay particles (<0.01 mm), were characterized as heavy clay-loam soil to extremely heavy clay soil and reference plots as loamy-sandy to extremely heavy clay. It was determined that the soil reaction was from 4.44 to 4.72 at experimental plots and from 5.17 to 6.28 at reference plots and soil organic carbon content was from 18.79–20.38 g/kg at experimental plots and from 5.01–18.75 g/kg at reference plots. Determined soil reaction was extremely acidic till strongly acidic at experimental plots and acidic till slightly acidic at reference plots (Regulation No 151/2016 2016). The monitored soils according to the humus content in the soil, calculated from above mentioned soil carbon content, were classified in case of the experimental plots as high level humus soils and in case of reference plots as low humus level soil till high level humus soil.

Average contents of heavy metals – Cd, Pb, Ni are shown in Tables 3, 4 and 5 in selected soil depths in experimental area of Dry Polder Beša and also in the reference area. It was found that the average content (average of depths and plots) of cadmium (Table 3) for both areas were on the same level (E – 0.040 mg/kg, R – 0.041 mg/kg). The average content (average of depths and plots) of lead was 0.088 mg/kg and nickel 2.0 mg/kg at experimental area and 0.062 mg/kg Pb, 0.86 mg/kg Ni at reference area. Content of Pb was 1.4 times higher (Table 4) at experimental area than at reference area and content of Ni was 2.3 times higher (Table 5) at experimental area than at reference area. Malisauskas and Sileika (2001) found higher contents of Pb and Ni by 20–40% in the polders of the river Nemunas on the flooded territories compared to no-flooded territories. Similarly, Wijnhoven *et al*. (2006) in observing often flooded territory along the river Rhine found that these territories have higher contents of total and available Pb compared to no-flooded territories.

River sediment is a major source of heavy metals pollution (Gustavson *et al*. 2008; Yi *et al*. 2011;

T a b l e 1

Recalculated background values of Cd, Pb and Ni in A horizon of soil units of Slovakia [mg/kg] and conversion factors [%] (Makovníková 2000; Tóth 2007) of heavy metals in soils of Slovakia used to calculate mobile fraction from total content

Soil type	Cd	Pb	Ni
Chermozems	0.04	0.30	0.27
Gleysols	0.06	0.44	0.42
Luvisols	0.04	0.42	0.20
Regosols	0.04	0.40	0.15
Conversion factor	0.20	0.02	0.01

T a b l e 2

Basic characteristics of sampling plots, soil depth 0–0.6 m

Parameter / Plot	Experimental area (E)			Reference area (R)		
	E1	E2	E3	R1	R2	R3
Soil type	Gleysols	Luvisols	Regosols	Luvisols	Chernozems	Gleysols
Plots area [ha]	9.30	33.80	29.90	33.20	39.40	13.40
Soil reaction [pH/KCl]	4.44	4.49	4.72	6.04	6.28	5.17
Organic carbon [g/kg]	18.79	21.59	20.38	5.01	13.65	18.75
Clay particles [%]	67.87	70.01	54.08	16.17	58.22	79.62
Evaluation of soil 0–0.6 m	Clay	Clay	Clay-loam	Loamy-sandy	Clay-loam	Clay

Besser *et al*. 2013). Sediment is the environmental reservoir, which accumulated contaminants gradually released back into the water, and thus pollutes the water flow and consequently neighbourhoods in a long period of time. The River Laborec is the only one inflow of Polder Beša. One part of the river Laborec was monitored in order to determine the content of heavy metals (Table 6). Based on our measurement of heavy metals concentrations in the sediment of the river Laborec it can be stated that the major source of heavy metals is sewage channel of former production. The mouth of sewage channel is situated above the sampling point Voľa 2. Sediment at this point contains the higher levels of Cd, Pb and Ni than at point above the mouth of sewage (sampling point Voľa 1). The monitoring was realised in 2000–2003 and it was found that the content of monitored heavy metals in the sediment of the river Laborec in either case did not exceed the maximum admissible concentrations valid in Slovakia (Cd 12 mg/kg, Pb 530 mg/kg, Ni 44 mg/kg; Methodical Direction No 549/1998-2 1998) and the measured levels do not pose an acute danger. The risk of contamination increases with the intensity of flooding. As it was previously mentioned Polder Beša was flooded six times by the year 2009. The gradual accumulation of sediment probably increased concentration of heavy metals in the flooded soil.

The content of heavy metals was affected by sampling plot in the reference area (ANOVA

Table 3

Cadmium content at experimental and reference area [mg/kg]

Sampling plot	Sampling depth [m]	Mean	SD[1]	Range		Median
				minimum	maximum	
E1[2]	0.0–0.2	0.064	0.038	0.029	0.117	0.045
	0.2–0.4	0.040	0.018	0.025	0.066	0.030
	0.4–0.6	0.022	0.014	0.011	0.042	0.012
	0.0–0.6	0.042	0.024	0.022	0.075	0.028
E2	0.0–0.2	0.050	0.031	0.012	0.089	0.050
	0.2–0.4	0.033	0.016	0.010	0.046	0.043
	0.4–0.6	0.024	0.010	0.010	0.031	0.031
	0.0–0.6	0.036	0.018	0.011	0.055	0.041
E3	0.0–0.2	0.063	0.038	0.014	0.108	0.067
	0.2–0.4	0.041	0.022	0.014	0.068	0.041
	0.4–0.6	0.028	0.020	0.010	0.055	0.018
	0.0–0.6	0.044	0.027	0.012	0.077	0.042
R1[3]	0.0–0.2	0.040	0.021	0.015	0.067	0.037
	0.2–0.4	0.037	0.022	0.013	0.067	0.032
	0.4–0.6	0.020	0.007	0.011	0.029	0.019
	0.0–0.6	0.032	0.017	0.013	0.054	0.029
R2	0.0–0.2	0.054	0.004	0.050	0.059	0.053
	0.2–0.4	0.051	0.002	0.048	0.054	0.050
	0.4–0.6	0.030	0.004	0.025	0.036	0.030
	0.0–0.6	0.045	0.001	0.043	0.046	0.046
R3	0.0–0.2	0.054	0.015	0.037	0.073	0.053
	0.2–0.4	0.045	0.011	0.031	0.059	0.046
	0.4–0.6	0.037	0.008	0.027	0.047	0.037
	0.0–0.6	0.046	0.011	0.032	0.060	0.045

[1]SD – standard deviation; [2]E1–E3 – experimental plot 1–3; [3]R1–R3 – reference plot 1–3

$P < 0.0001$, F: $F^{Cd\text{-}R} = 11.21$; $F^{Ni\text{-}R} = 75.68$; $F^{Pb\text{-}R} = 10.76$) and in the case of nickel also in the experimental area (ANOVA $P < 0.0001$, F: $F^{Ni\text{-}E} = 60.95$). The measured heavy metals concentrations are within a wide range, indicating a considerable spatial variability. On one hand, the spatial variation was ascribed to the geochemical inherent characteristics (Wilcke *et al.* 2005). On the other hand, experimental plots are much closer to the Laborec River or Latorica River than reference plots. Different hydrological conditions would affect soil physio-chemical properties (e.g., soil salinity) and then alter the mobility of heavy metals in soil (Acosta *et al.* 2011).

The content of heavy metals in the soil is also influenced by the others soil parameters, organic carbon correlates with enhanced levels of heavy metals (De Temmerman *et al*. 2003; Gandois *et al*. 2010; Józefowska *et al*. 2014). Statistically significant correlation between the Cd, Pb content and soil organic carbon (r – in the range of 0.41 to 0.47, $p < 0.05$) was found also at our study in both monitored areas (Table 7). Relationships between content of soil organic carbon and Ni were significant only at experimental area ($r = 0.68$, $p < 0.05$). The effect of soil depth on heavy metals content was significant, too (ANOVA, $P < 0.0001$, F:$F^{Cd\text{-}E} = 15.59$; $F^{Cd\text{-}R} = 22.20$; $F^{Ni\text{-}E} = 87.78$; $F^{Ni\text{-}R} = 72.89$; $F^{Pb\text{-}E} = 15.19$; $F^{Pb\text{-}R} = 129.15$). The content of heavy metals decreased with increasing depth of soil. The difference between the content of determined metals in the mini-

T a b l e 4

Lead content at experimental and reference area [mg/kg]

Sampling plot	Sampling depth [m]	Mean	SD[1]	Range		Median
				minimum	maximum	
E1[2]	0.0–0.2	0.110	0.053	0.035	0.149	0.145
	0.2–0.4	0.076	0.039	0.030	0.125	0.073
	0.4–0.6	0.044	0.013	0.027	0.057	0.048
	0.0–0.6	0.076	0.034	0.030	0.109	0.090
E2	0.0–0.2	0.118	0.025	0.083	0.140	0.130
	0.2–0.4	0.097	0.031	0.060	0.136	0.095
	0.4–0.6	0.068	0.014	0.050	0.084	0.069
	0.0–0.6	0.094	0.023	0.064	0.120	0.098
E3	0.0–0.2	0.120	0.080	0.040	0.230	0.090
	0.2–0.4	0.100	0.065	0.040	0.190	0.069
	0.4–0.6	0.064	0.033	0.033	0.110	0.050
	0.0–0.6	0.095	0.060	0.038	0.177	0.069
R1[3]	0.0–0.2	0.070	0.001	0.069	0.072	0.069
	0.2–0.4	0.060	0.004	0.055	0.066	0.060
	0.4–0.6	0.046	0.001	0.045	0.047	0.046
	0.0–0.6	0.059	0.002	0.057	0.061	0.058
R2	0.0–0.2	0.070	0.016	0.051	0.090	0.069
	0.2–0.4	0.068	0.004	0.063	0.072	0.068
	0.4–0.6	0.045	0.008	0.036	0.055	0.043
	0.0–0.6	0.061	0.009	0.050	0.072	0.060
R3	0.0–0.2	0.071	0.007	0.062	0.080	0.071
	0.2–0.4	0.075	0.004	0.070	0.080	0.074
	0.4–0.6	0.052	0.000	0.051	0.052	0.052
	0.0–0.6	0.066	0.001	0.064	0.067	0.066

[1]SD – standard deviation; [2]E1–E3 – experimental plot 1–3; [3]R1–R3 – reference plot 1–3

mum and maximum depth of soil was 0.035 mg/kg Cd, 0.057 mg/kg Pb and 1.39 mg/kg Ni in the experimental area and 0.020 mg/kg Cd, 0.023 mg/kg Pb and 0.79 mg/kg Ni in the reference area. Decreasing content of Cd and Ni with increasing depth is consistent with the findings of Maliszewska-Kordybach *et al*. (2012). Some researchers pointed out that heavy metals such as As, Cu, Pb and Zn decreased with increasing depths (Prusty *et al.* 2007; Bai *et al.* 2014), which might be associated with plant cycling because plant growth would lead to trace elements upwards movement throught plant litters and return to surface soils (Gregorauskiené & Kadűnas 2006). This mechanism can be used to explain the vertical distribution pattern in this study.

Relationship between content of heavy metals in the soil and soil reaction was not significant (Table 7). Correlation between the soil reaction and Cd and Ni was antithetical, and direct correlation was between the soil reaction and Pb. Similarly Józefowska *et al*. (2014) found not significant relationship between soil reaction and contents of Cd and Pb in the soil. Content of Pb in soil significantly correlated with the content of Cd ($r^E = 0.68$; $r^R = 0.68$, $p < 0.05$) at both monitored areas and with Ni (r = 0.58) only at reference area (Table 7). Relationship between Cd and Ni was insignificant (in that case antithetical correlation), what in the same conditions of soil found also De Temmerman *et al*. (2003). Antithetical correlation (insignificant) was

T a b l e 5

Nickel content at experimental and reference area [mg/kg]

Sampling plot	Sampling depth [m]	Mean	SD[1]	Range		Median
				minimum	maximum	
E1[2]	0.0–0.2	2.49	0.56	1.86	3.23	2.38
	0.2–0.4	2.38	0.46	1.96	3.02	2.17
	0.4–0.6	1.08	0.16	0.86	1.23	1.16
	0.0–0.6	1.98	0.37	1.56	2.47	1.92
E2	0.0–0.2	3.48	0.46	3.01	4.10	3.34
	0.2–0.4	2.76	0.53	2.36	3.50	2.41
	0.4–0.6	1.59	0.42	1.02	2.00	1.75
	0.0–0.6	2.61	0.42	2.25	3.20	2.37
E3	0.0–0.2	1.85	0.20	1.58	2.07	1.91
	0.2–0.4	1.43	0.35	1.11	1.92	1.26
	0.4–0.6	0.98	0.36	0.50	1.37	1.08
	0.0–0.6	1.42	0.28	1.06	1.73	1.47
R1[3]	0.0–0.2	1.52	0.43	1.05	2.10	1.42
	0.2–0.4	1.10	0.30	0.72	1.46	1.12
	0.4–0.6	0.51	0.02	0.49	0.53	0.52
	0.0–0.6	1.04	0.24	0.76	1.35	1.02
R2	0.0–0.2	0.46	0.14	0.29	0.64	0.45
	0.2–0.4	0.43	0.15	0.26	0.62	0.41
	0.4–0.6	0.27	0.10	0.17	0.40	0.25
	0.0–0.6	0.39	0.13	0.24	0.55	0.37
R3	0.0–0.2	1.63	0.10	1.52	1.76	1.61
	0.2–0.4	1.37	0.13	1.28	1.55	1.28
	0.4–0.6	0.45	0.21	0.20	0.72	0.44
	0.0–0.6	1.15	0.14	1.00	1.34	1.11

[1]SD – standard deviation; [2]E1–E3 – experimental plot 1–3; [3]R1–R3 – reference plot 1–3

found between the soil reaction and Cd, Ni content. Correlation between the soil reaction and Pb content direct but insignificant, too.

Above mentioned spatial variation in the content of Cd, Pb and Ni in the soils of monitored area makes it difficult to analyse their degree of contamination without taking into account the spatial variability of metals and their content in the parent materials of soil, that is the natural background. Geo-accumulation index (I_{geo}) is an index to assess the status and degree of heavy metal pollution in the soils (Asaah *et al.* 2006; Zhang *et al.* 2017). Heavy metals contents in the soils were used as background values (Table 1) to calculate the enrichment levels for heavy metals in the soils. In general, Ni appear to be the contaminated element in all study area as presented Table 8, showing the highest I_{geo} classes for all sampling plots at soil depth 0–0.2 m. For Cd and Pb, the geo-accumulation index was less than zero (I_{geo} < 0). Therefore, the soil investigated was qualified uncontaminated by Cd and Pb. Then, the concentrations of cadmium and lead in these soils may only be associated to the geochemical weathering (natural source). The results showed (Table 9)

T a b l e 6

Content of heavy metals in the sediment of river Laborec (2000–2003)

Sampling point	Heavy metals [mg/kg]	Mean	SD	Range		Median
				minimum	maximum	
Voľa 1[1]	Cd	0.231	0.074	0.133	0.312	0.240
	Pb	16.36	3.20	11.12	19.20	17.56
	Ni	8.04	1.21	6.30	9.53	8.16
Voľa 2[2]	Cd	0.706	0.098	0.538	0.780	0.754
	Pb	51.05	8.64	41.95	61.20	50.53
	Ni	13.88	1.08	12.98	15.73	13.40
Michalovce	Cd	0.521	0.049	0.472	0.601	0.505
	Pb	45.54	3.94	40.97	49.83	45.67
	Ni	9.18	1.72	7.83	12.13	8.38

[1]sampling point before the mouth of sewage channel; [2]sampling point after the mouth of sewage channel

T a b l e 7

Correlation matrix among heavy metal contents, soil reaction and soil organic carbon content of the studied area

Area	Parameter	Cd	Pb	Ni	pH/KCl	SOC
Experimental area	Cd	–	–	–	–	–
	Pb	0.68^{++}	–	–	–	–
	Ni	–0.02	0.26	–	–	–
	pH/KCl	–0.05	0.06	–0.17	–	–
	SOC	0.42^{+}	0.41^{+}	0.68^{++}	–0.01	–
Reference area	Cd	–	–	–	–	–
	Pb	0.48^{+}	–	–	–	–
	Ni	–0.04	0.58^{++}	–	–	–
	pH/KCl	–0.03	0.04	–0.28	–	–
	SOC	0.43^{+}	0.47^{+}	0.29	$–0.39^{+}$	–

Cd – cadmium content; Pb – lead content; Ni – nickel content; pH/KCl – soil reaction; SOC – soil organic carbon content; ^{+}P = 0.01– 0.05; ^{++}P < 0.01

that I_{geo} values for Ni were higher than zero and were higher at experimental plots than at reference plots. I_{geo} values for Ni were ranged between 0.11 and 2.29 at reference plots and between 1.95 and 3.53 at experimental plots. This indicate that the given soils are contaminated by Ni derived from anthropogenic sources. In descending orders, the contamination of soils of studied area can ranged as follows: Ni > Cd > Pb. Accordingly, it can be observed that Luvisols were more contaminated by Ni than Regosols, Regosols more than Gleysols and Gleysols more than Chernozems.

Trace metals in the soils mainly originate from the natural soil weathering and anthropogenic activities. When comparing with the metals from natural sources, the pollution contribution from anthropogenic sources can be quantified for every sample. In this study the positive differential between the measured concentration of Ni (C_{Ni}) and background values for Ni (Table 1) indicates the anthropogenic input, and the anthropogenic contribution rate (ACR) according to background value for Ni (B_{Ni}) can be calculated using the following equation:

$$\%\ Ni_{anthropogenic} = (C_{Ni} - B_{Ni}) / C_{Ni}\ x\ 100$$

According to anthropogenic Ni rate equation, the average values of ACR were estimated to 41.30%, 74.23% and 86.87% for reference plots R2, R3 and R1, respectively, and 83.13%, 91.91% and 94.26% for experimental plots E1, E3 and E2 respectively. ACR for Ni in experimental plots were 1.331 times higher than the ACR for Ni in reference plots. All the sampling plots are located nearby thermal power station, therefore pollution may emanate from the production. Moreover Dry Polder Beša occasional flooding by the Laborec River may cause Ni pollution by the sediment, it was mentioned above.

In addition to the human food production and animal feed production, it is desirable to compare the measured concentrations with the critical values, in

T a b l e 8

Graphical representation of geo-accumulation index of metals in the soils of Dry Polder Beša and reference area, calculated for soil depth 0–0.2 m

I_{geo} Classes			Sample plot	Cd	Pb	Ni
				experimental area		
0	< 0 = practically unpolluted		E1			
1	> 0–1 = unpolluted to slightly polluted		E2			
2	> 1–2 = slightly polluted		E3			
3	> 2–3 = slightly to high polluted			reference area		
4	> 3–4 = high polluted		R1			
5	> 4–5 = high to strongly polluted		R2			
6	> 5 = strongly polluted		R3			

T a b l e 9

Geo-accumulation index of heavy metals in Dry Polder Beša soils and soils of reference area, calculated for soil depth 0–0.2 m

Pollutant	Experimental area			Reference area		
	E1	E2	E3	R1	R2	R3
	Gleysols	Luvisols	Regosols	Luvisols	Chernozems	Gleysols
Cd	–0.75	–0.67	–0.36	–0.85	–0.16	–0.78
Pb	–2.86	–2.46	–2.68	–3.17	–2.72	–3.22
Ni	1.95	3.53	3.03	2.29	0.11	1.37

relation to transfer of contaminants from the soil to the plant, recommended by Slovak Regulation. Presented results indicate that the concentrations of Pb and Ni were higher than the critical values only at experimental area. For cadmium it does not apply because average cadmium content at experimental area did not exceed limit value. Critical limits of heavy metals, in relation soil – plant, is for Ni 1.5 mg/kg and for Pb and Cd 0.1 mg/kg (Regulation No 508/2004 2004).

CONCLUSIONS

Ecological stability of polder is disturbed by artificial flooding in case of extreme flood flows. The heavy metal concentrations in the soil were higher 2.3 times for Ni and 1.4 times for Pb at occasionally flooded area (Dry Polder Beša) than in the soil at no flooded reference area. The significant difference in Cd content was not found in the investigated territory. The variability of heavy metals content in the soil was also significantly influenced by soil depth and heavy metal content correlate with soil organic carbon content. The geo-accumulation index values indicate that the soils are contaminated by the Ni from anthropogenic sources. Accordingly, it can be observed that Luvisols were more contaminated by Ni than Regosols, Regosols more than Gleysols and Gleysols more than Chernozems. Cd and Pb occurrence in these soils may be associated to the geochemical weathering. The value of the Antropogenic contribution rate indicate that anthropogenic input of Ni was 1.331 times higher in flooded area than in reference no flooded area. Antropogenic pollution founded on both investigated areas indicate, that there must exist additional source of Ni pollution. The probable source of contamination is the thermal power station. From the point of view of using the Dry Polder for agricultural production, it is desirable to compare the measured concentrations with the critical values recommended by regulations in relation to transfer of contaminants from the soil to the plant. Presented results indicate that the concentrations of Pb and Ni in the soils were higher than the critical values only at flooded area. For Cd it does not apply because average cadmium content at flooded area did not exceed limit value.

We point out that occasionally flooded polders need regular monitoring of heavy metals content in the soil. Moreover, the influencing mechanisms of heavy metals input by plants must be applied in the future.

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