Report on the impact of anthropogenic factors on the properties and functions of soils from a selected area of Central European Lowland province

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Abstract

Purpose The study aims to assess the impact of human activity on the content and migration of trace elements in soil profiles of various physico-chemical properties. The research hypothesis assumed that human impact related to the functioning of buildings, agriculture, industry and communication negatively affected the trace element contents and physico-chemical properties of soils in a selected urban area (the Grudziądz Basin).

Materials and methods Seven soil exposures were made in areas that differed in land use and soil type over an area totalling approx. 200 ha. In the soil profiles, samples of soil of disturbed structure were taken from each genetic horizon. Selected physico-chemical properties of soils were determined: soil texture, soil pH, TOC, $CaCO_3$ content. The total content of heavy metals in the soils was determined by AAS after digestion in hydrofluoric acid and bioavailable forms in 1 M DTPA. The sources of elements in the studied soils were assessed using the following indices: Enrichment Factor (EF), Geoaccumulation Index (Igeo) and Contamination Factor (CF).

Results and discussion The sand fraction dominated the examined soil profiles, with its content ranging widely and averaging 64.7%. In general, the humus horizons had lower pH values than the deeper layers and parent rock horizons. The organic carbon content ranged from 0.07 to 4.64%. The vertical decomposition of total N was strongly related to the decomposition of organic carbon. The highest metal contents in the soil samples were for zinc, and then for nickel. Conversely, the lowest concentrations were for mercury. Most of the profiles had higher contents of the analysed elements in their upper horizons. The humus horizons were characterised by the accumulation of Cr, Hg, Zn and Fe. The samples from the soil profiles were highest in bioavailable forms of zinc and nickel.

Conclusions The assessment of human impact on the concentrations and migration of trace elements in profiles of agricultural soils found the contents of heavy metals to be variable. Only in a few profiles were EF values for Cd, Pb and Ni found to indicate the effects of human activity. Likewise, CF and Igeo attest to only slight contamination in the research area.

Keywords Soil profiles · Trace elements · Pollution indices · Anthropogenic factors

1 Introduction

The trace element contamination of soil is an indicator of environmental quality. Soils are a major host for the accumulation of elements, including trace elements, as well as acting as a natural filter preventing elements from penetrating into the soil profile.

Trace elements are mainly associated with the clay fraction in most soils, and a high content of organic matter. Therefore, loamy soils are more abundant in these elements than are sandy soils, which have low sorption capacity and acid reaction (Acosta et al. 2010; Kabata-Pendias 2011).

Trace elements occur naturally in the environment. They derive from parent rock, organic matter, sediments and precipitation. They can occur in soil as a result of anthropogenic activities. Increases in heavy-metal contents in the environment significantly affect the chemical composition of plants, as well as disturbing the natural balances between

the various minerals in plants (Okereafor et al. 2020). The main industries they derive from are chemical, pulp and paper, electrotechnical, glass, ceramics, asbestos, iron and steel, non-ferrous metal, aluminium metallurgy, oil refining, coal-fired power and the coke industry. Over the years, much research has been done on the impact that various industries have on soil. It has been shown that the range of impact of industrial emissions can be up to 50 km, though the greatest changes have been demonstrated to occur in the immediate vicinity of the emitters (Fruzińska 2011; Kabata-Pendias 2011; Borrelli et al. 2020; Naidu et al. 2021). The concentration of heavy metals in soils is equally affected by road transport (Jaworska et al. 2015). Research shows a significant statistical correlation between trace element contents in soils and distance from emission source (a road). Another source of anthropogenic impact on trace element contents in soil is agricultural production. The main sources of contamination of agricultural land are mineral fertilisers, pesticides and plant protection products, as well as waste from industrial-scale pig, cattle and poultry farms. The heavy use of chemicals in agriculture, mainly as mineral fertilisers containing trace elements, introduces them into the soil, thereby increasing their contents. The mineral fertilisers that are most heavily contaminated with trace elements are in order of contamination level: phosphorus > calcium > potassium > nitrogen fertilisers. From the perspective of protecting the soil environment, it is important to also study areas potentially exposed to lower pollutant emissions. Trace elements occur in soils in the form of various chemical compounds with various types of bonds. Contaminated soils contain more mobile forms of trace elements. This is due to the processes of sorption, chelation and co-precipitation with soil particles. Thus, under specific physico-chemical conditions, the pool of bioavailable metals increases. The changeability of conditions allows trace elements present in soils to be transformed into mobile forms. Therefore, in environmental, agricultural and geochemical studies, in addition to determining the total amount of metals accumulated in soils, it is important to collect data on their mobility and bioavailability to plants. The content of bioavailable forms of a given element depends in part on the total content (Czarnowska and Kozanecka 2001; Niesiobędzka 2005).

It is important to study how the migration of heavy metals relates to soil composition, grain size and organic matter content (including the various forms of organic carbon).

The research hypothesis assumed that production plants, housing and service facilities, local roads and agricultural areas located in the area covered by the research may negatively affect the properties of the surrounding soils.

The aim of the research was to determine the physical and chemical properties of soils, including the content and profile distribution of trace elements in soils subjected to anthropopressure.

2 Methods and materials

2.1 Study area and soil sampling

According to the division proposed by Kondracki (2009), the research area is located in the Grudziądz Basin mesoregion, in the Lower Vistula River Valley macroregion of the Southern Baltic Lake Districts sub-provinces of the Central European Lowland province (Fig. 1). According to Drozdowski (1974), the Grudziądz Basin traces its origins to the glacial stage of the last glaciation and is associated with glacial erosion by the ice sheet. The area lies in a temperate climate zone and is characterised by a high temporal variability in meteorological and climate parameters. Annual precipitation ranges from 295 to 757 mm. South-westerly winds predominate and wind directions are conditioned by the orientation of the Vistula valley.

According to Journal of Laws of 2016 item 71, the industrial activities carried out here are classed as posing a permanent threat of environmental impact. The research area is partly crossed by a highway, whose adjacent soils are exposed to contamination with substances from fuel combustion and the abrasion of the road surface and vehicle tires. A significant portion of the area is covered by agricultural land (both arable and pasture) where agrotechnical treatments are applied that may affect the physical and chemical properties of the soil.

Seven soil exposures were made in areas that differed in land use and soil type over an area totalling approx. 200 ha (Fig. 2). In the soil profiles, samples of soil of disturbed structure were taken from each genetic horizon. For each plot, geographic coordinates (x, y) were defined. Point locations were determined in the field using a GPS receiver (Fig. 2).

To describe the soil morphology, before field research began, we analysed topographic maps, orthophotomaps, detailed geological maps of Poland, and soil and agricultural maps. The locations of the soil profiles were selected based on these analyses and in-field observations. Then, after verifying morphological features, this description was corrected in the laboratory based on the Polish Soil Classification (PTG 2011) and the World Reference Base for Soil Resources (WRB 2016).

2.2 Laboratory analysis

In air-dry soil samples, after sieving through a 2-mm mesh, the following analyses were performed:

- Grain-size composition by laser diffraction using a Malvern Mastersizer 2000E (ISO 13320 2009).
- Soil reaction as pH in extracts in H_2O and in 1 M KCl (ISO 10390 2005) by potentiometric method using a CPC-551 pH meter (ISO 10390 2005).

Fig. 1 Research area located in the Grudziądz Basin mesoregion
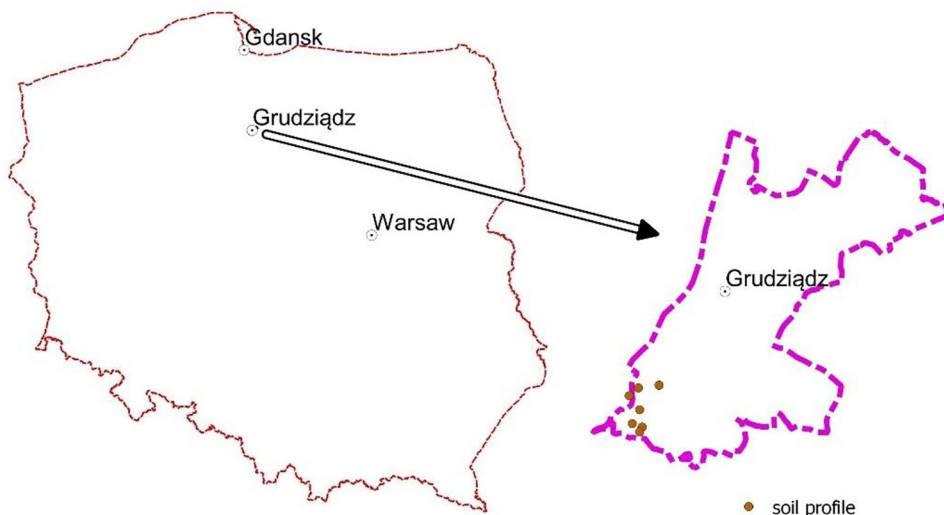
• soil profile

• Hydrolytic acidity by Kappen method (Kabała and Karczewska 2017).
• Organic carbon and total nitrogen contents for 25 samples from the soil profiles using a VarioMAX CN analyser according to ISO 10694 (1995).
• Calcium carbonate content by Scheibler method according to ISO 10693 (1995).
• Total heavy-metal contents after mineralisation in Teflon crucibles in a mixture of HF and $HClO_4$ acids by Crock and Severson (1980) method using the ASA method on a SOLAR 969 apparatus (Unicam).
• Bioavailable forms of heavy metals in soil samples by Lindsay and Norvell's (1978) method using 1 M diethylenetriamine pentaacetic acid (DTPA) as an extractant by ASA method using a SOLAR 969 apparatus (Unicam).
• Mercury content in soil by atomic absorption spectrometry using an AMA 254 analyser.

All analyses were performed in triplicate. The paper presents the arithmetic means of the results. The results were additionally verified using Till-3 certified material.

2.3 Statistical analyses

Calculations were performed in Statistica 12 software. The tests were performed on data from the soil samples obtained from the soil profiles. To summarise the data, basic descriptive statistics were performed specifying minimum and maximum arithmetic means ($\grave{x}$), kurtosis, standard deviation (SD) and coefficient of variation (CV).

Pearson's correlation coefficients (at $p < 0.05$) were used to determine the relationship between analysed elements and the selected physico-chemical properties of the soils.

The Shapiro–Wilk test was performed to determine the probability that the sample came from a normally distributed population.

2.4 Pollution indices

The sources of elements in the studied soils were assessed using the following indices: Enrichment Factor (EF), Geoaccumulation Index (Igeo) and Contamination Factor (CF).

EF is calculated by normalising the concentration of a single metal in the soil with respect to the concentration of a reference element. The reference element is one that is particularly stable in soil and characterised by a lack of vertical mobility and/or degradation phenomena (Ackerman 1980). Studies make wide use of Fe, Al, Mn and Rb as typical elements, and of total organic carbon and grain size (Ackerman 1980; Loring et al. 1995). This way, the degree of accumulation of other metals in the soil profile layers can be determined relative to the concentration of the reference element. The calculations employ the content levels of individual metals, which are defined as the background values. EF is determined according to the formula:

$$EF = \frac{(M/Fe)\ in\ a\ genetic\ layer}{(M/Fe)\ background\ value}$$

where: M = total metal content, Fe = total iron content.

According to Chen and Guo (2017), EF values were divided into seven classes as follows:

EF < 1   enrichment not indicated\
EF < 3   slight enrichment
EF = 3–5   moderate enrichment
EF = 5–10   moderately severe enrichment

Fig. 2 Samples of soil of disturbed structure taken from each genetic horizon

profile	Geographic coordinates	
	x	y
1	18° 43' 10.943" E	53° 26' 45.784" E
2	18° 42' 35.222" E	53° 25' 53.924" E
3	18° 42' 40.033" E	53° 25' 59.263" E
4	18° 42' 15.721" E	53° 26' 33.926" E
5	18° 42' 21.650" E	53° 26' 3.072" E
6	18° 42' 32.565" E	53° 26' 42.752" E
7	18° 42' 35.313" E	53° 26' 18.478" E

EF = 10–25　　severe enrichment
EF = 25–50　　very severe enrichment
EF > 50　　　extremely severe enrichment

Enrichment factors between 0.5 and 1.5 reflect natural content of elements resulting from soil processes. An enrichment factor above 1.5 indicates anthropogenic accumulation of metallic elements (Zhang and Liu 2002).

The index describing the degree of soil contamination with metals is the Geoaccumulation Index (Igeo). It was originally defined by Müller (1969) for metal concentrations in the two-micron fraction. It is used to compare contents of metallic elements in tested soil material against natural metal concentrations. The geoaccumulation index is calculated according to the formula:

$$I-geo = log\ (Cn/(1.5 \times Bn))$$

where Cn = measured concentration of heavy metal in soil, Bn = geochemical background value, 1.5 = natural variation in the concentration of a metal in an environment of low human impact; Cn is the concentration of a metal in the soil reference to calculated values and Bn to background values; the factor 1.5 is applied to order control the variations of Bn values caused by the environment.

The applied geochemical background values were derived from the analysis of the determined content in the parent material (Table 1).

Geoaccumulation Index:

Igeo ≤ 0　　　　unpolluted
0 < Igeo < 1　　unpolluted to moderately polluted
1 < Igeo < 2　　moderately polluted
2 < Igeo < 3　　moderately to highly polluted
3 < Igeo < 4　　highly polluted
4 < Igeo < 5　　highly to extremely polluted
Igeo ≥ 5　　　　extremely polluted

The Contamination Factor (CF) assesses anthropogenic effects on the soil environment. It is calculated according to the following formula:

$$CF = \frac{total\ metal\ content}{geocheical\ background\ value}$$

where (Håkanson 1980):

Table 1 Geochemical background value used in calculations

Profile	Cr (mg·kg^{-1})	Cu	Zn	Ni	Cd	Pb	Fe (g·kg^{-1})
IV Silts	28.98	11.39	79.54	29.82	0.37	25.52	57.08
I, II, III, VI, VII Sand	7.46	4.79	12.74	7.18	0.52	13.79	7.86
V Loamy sand	17.53	3.97	25.88	13.00	0.52	15.48	19.73

CF < 1   low contamination factor
1 ≤ CF < 3   moderate contamination factor
3 ≤ CF < 6   significant contamination factor
CF ≥ 6   very high contamination factor

3 Results and discussion

3.1 Morphology and systematics of soil profiles

Based on the analyses and in-field observations, the locations of soil profiles were selected (Fig. 2) and soil exposures were performed. Then, after verifying the

morphological features of the identified soil horizons, the studied soils were classified as Cambisols (profile I, VI), Fluvisols (profile II, III, IV) and Luvisols (profile V, VII) (IUSS Working Group WRB 2015).

3.2 Physico-chemical soil properties

Grain size is a basic soil property. The absolute and relative sizes of soil grains play an important role as they affect many of the properties of a soil, and particularly physical and physico-chemical properties, and thus their utility (Uziak and Klimowicz 2000). Grain-size distribution analysis used alongside the identification of physico-chemical properties allows the genesis and soil-forming processes of

Table 2 Texture

Genetic horizons	Depth (cm)	Gravel and stones (%)	Fraction (%)			Granulometric subgroup symbol(USDA)
			Sand (2.0–0.05 mm)	Silt (0.05–0002 mm)	Clay (< 0.002 mm)	
Profile I						
Ap	0–20	5.5	76.56	21.05	2.39	Loamy sand (LS)
C	20–150	11.1	83.2	14.66	2.14	Loamy sand (LS)
C1	> 150	10.4	84.96	13.16	1.88	Loamy sand (LS)
Profile II						
Ap	0–25	3.0	57.92	38.81	3.27	Sandy loam (SL)
Bw	25–50	2.0	52.64	44.15	3.21	Sandy loam (SL)
C	50–150	1.0	91.8	7.55	0.65	Sand (S)
Profile III						
Ap	0–35	2.8	67.82	28.89	3.29	Sandy loam (SL)
Bw	35–58	1.8	72.79	24.97	2.24	Loamy sand (LS)
C	58–150	1.3	96.22	3.66	0.12	Sand (S)
Profile IV						
A	0–19	1.3	34.33	60.78	4.89	Silt loam (SiL)
Bvg	19–80	0.0	17.05	75.44	7.51	Silt loam (SiL)
Cg	80–150	0.0	3.13	84.64	12.23	Silt loam (SiL)
Profile V						
Ap	0–25	2.0	39.82	55.37	4.81	Silt loam (SiL)
A	25–75	1.7	67.01	29.81	3.18	Sandy loam (SL)
Et	75–98	0.0	76.14	20.54	3.32	Loamy sand (LS)
Btg	98–120	2.0	39.82	55.37	4.81	Loamy sand (LS)
Cg	120–150	1.7	67.01	29.81	3.18	Sandy loam (SL)
Profile VI						
Ap	0–58	4.5	68.34	28.51	3.15	Sandy loam (SL)
Bw	58–68	8.7	81.85	15.85	2.30	Loamy sand (LS)
Ck	68–150	3.9	92.23	6.85	0.92	Sand (S)
Profile VII						
Ap	0–13	13.8	52.20	43.75	4.05	Sandy loam (SL)
A	13–43	21.6	59.56	33.74	6.70	Sandy loam (SL)
Et	43–64	19.3	56.35	38.32	5.33	Sandy loam (SL)
Bt	64–80	18.2	34.05	55.81	10.14	Silt loam (SiL)
C	80–150	16.0	63.14	31.42	5.44	Sandy loam (SL)

a region's soils to be estimated. The sand fraction dominated the examined soil profiles, with its content ranging widely (Table 2) and averaging 64.7%. The average silt content was 34.5%, and the clay fraction averaged 4.0%. The soils in the study area were found to vary greatly in grain size, which may result from the diverse geomorphological structure. The grain size of the soils is clearly dependent on the geological formations from which they were created (Kabata-Pendias 2011). On the floodplain terraces, sands with a small amount of clay and silt dominate, and in the areas that have been flooded and separated from the Vistula by a flood bank, silt dominates. River meadows are classified as intrazonal soils that are influenced by climatic factors (as zone soils are), but largely depend on local conditions, i.e. water relations and geochemical factors (Bednarek and Prusinkiewicz 1999). They are distinguished by a strongly acidic reaction and a small clay fraction (Kabata-Pendias 2011).

In the tested samples from soil profiles, the pH_{H2O} value ranged from pH 5.33 to 8.36. The lowest pH_{H2O} value was

determined in a soil sample taken from the humus horizon of profile No. II, and the highest in a sample from the parent rock of profile VI (Table 3).The pH_{KCl} in the analysed samples from the soil profiles ranged from pH 4.32 to 8.04. The reaction was lowest in a sample from the parent rock of profile IV and highest in a sample from the profile VI parent rock (Table 3). In general, the humus horizons had lower pH values than the deeper layers and parent rock horizons.pH was highest for soil samples from soil profile No. VI, which was classified as a Cambisol. The hydrolytic acidity (Hh) was similar across profiles and ranged from 0.02 to 2.50 cmol(+)·kg^{-1}. It usually decreased with depth, being highest in humus horizons (Table 3).

The calcium carbonate content was varied. It was highest in a soil sample from profile V, at 3.98%, which may be due to the soil having been limed.

The organic carbon content in the tested samples from the soil profiles ranged from 0.7 to 46.4 g·kg^{-1}. In general, organic carbon content decreases down through the

Table 3 Physico-chemical properties of soils

Genetic horizons	Depth (cm)	pH		CaCO$_3$ (%)	OC (g·kg^{-1})	N total (g·kg^{-1})	C:N	Hh (cmol(+)·kg^{-1})
		H$_2$O	KCl					
Profile I								
Ap	0–20	6.83	6.44	< 1	6.2	0.5	13	0.6
C	20–150	7.74	7.58	2.15	4.2	0.1	42	0.2
C1	> 150	7.95	7.8	3.22	6.8	0.1	68	0.2
Profile II								
Ap	0–25	5.33	4.33	< 1	31.9	2.8	11	0.3
Bw	25–50	6.08	5.42	< 1	46.4	6.4	7	2.3
C	50–150	7.12	6.53	< 1	0.7	0.1	7	2.5
Profile III								
Ap	0–35	5.44	4.32	< 1	16.0	1.1	15	1.3
Bw	35–58	6.10	5.33	< 1	10.0	0.4	25	0.5
C	58–150	6.74	5.86	< 1	0.7	0.1	7	1.4
Profile IV								
A	0–19	5.88	4.97	< 1	16.0	2.6	7	0.9
Bvg	19–80	6.92	5.86	< 1	13.9	2.3	6	0.5
Cg	80–150	7.58	6.55	< 1	13.3	2.0	7	0.5
Profile V								
Ap	0–25	7.55	7.11	3.98	16.0	1.7	10	0.5
A	25–75	8.08	7.62	< 1	2.0	0. 2	10	0.1
Et	75–98	8.06	7.95	< 1	1.3	0.1	13	0.2
Btg	98–120	8.36	7.25	< 1	1.3	0.1	15	0.2
Cg	120–150	7.09	6.66	< 1	1.3	0.3	5	0.4
Profile VI								
Ap	0–58	7.27	6.94	< 1	14.0	1.0	10	0.2
Bw	58–68	7.40	6.60	< 1	1.7	0.1	17	0.3
Ck	68–150	8.12	8.04	1.13	4.8	0.1	148	0.1
Profile VII								
Ap	0–13	7.25	6.92	< 1	32.9	12.4	14	0.3
A	13–43	8.03	7.48	2.17	16.1	8.4	0.9	0.2
Et	43–64	7.62	7.29	1.13	16.1	0.7	23	0.2
Bt	64–80	8.12	7.39	2.34	16.1	0.2	80	0.2
C	80–150	8.02	7.53	1.75	13.1	0.2	66	0.02

soil profile. The exception is profile II, where organic carbon content was greater in the subsurface horizon, which is due to the tested soil being a Eutric Fluvic Cambisol (WRB 2016), which is characterised by irregular enrichment in humus and to its agricultural use. The development of soil when the water table is lowered (e.g. on river terraces) increases the oxygenation of subsurface layers and increases biological activity below the humus level. In the tested soils, the organic carbon content was below 35 g·kg^{-1}. According to international conventions, humus content below 35 g·kg^{-1} (approx. 20 g·kg^{-1}OC) is taken as a sign of desertification (Gonet 2007). Accordingly, 89% (by area) of Polish agricultural soils should be classified as being low in organic matter content and/or drought-affected. The degree of mineralisation of humus in the soil is directly dependent on how much mineral nitrogen is supplied by plants. In the studied soil profiles, the total nitrogen content decreased with depth (except in profile II) and ranged from 0.1 to 18.4 g·kg^{-1} (Table 3) The vertical decomposition of total N was strongly related to the decomposition of organic carbon. The nitrogen content in Polish soils is 0.2–20 g·kg^{-1}. The amount of nitrogen present in soil fractions depends mainly on meteorological conditions and agrotechnical treatments. The dynamics of nitrogen are determined primarily by meteorological conditions (temperature, precipitation) and the rhythm of plant development and the forms of nitrogen fertilisers used (Trawczyński 2016; Dromantienė et al. 2020). The C:N ratio in the soil profiles tended to decrease down through the soil profile (Table 3), probably reflecting the greater decay and older age of the humus.

The calculated C:N ratio varied widely, from 0.9:1 (sample from soil profile VII) to 148:1 (sample from soil profile VI). Researchers (Bednarek et al. 2004; Callesen et al. 2007) emphasise that the lower the C:N ratio in the mineralised material, the faster the organic matter decomposes.

The physico-chemical properties of soil affect the distribution of heavy metals in the environment. The size of soil aggregates has a significant impact on the heavy-metal contents in the soil. Heavy-metal concentrations in soils and

Table 4 Total content of heavy metals in soil profiles

Depth (cm)	Cr (mg·kg^{-1})	Cu	Zn	Ni	Cd	Pb	Hg	Fe (g·kg^{-1})
Profile I								
0–20	11.56	4.85	21.56	7.12	0.38	17.63	0.049	57.22
20–150	10.89	5.63	14.48	7.51	0.53	13.48	0.021	7.77
> 150	10.63	2.14	12.04	9.15	0.55	14.59	0.013	7.84
Profile II								
0–25	12.78	5.70	35.53	10.74	0.58	15.51	0.055	12.24
25–50	12.29	7.19	27.99	12.21	0.57	15.96	0.058	13.10
50–150	7.14	2.51	8.63	4.10	0.51	7.45	0.005	5.43
Profile III								
0–35	11.08	2.63	31.78	7.80	0.55	11.41	0.029	7.32
35–58	11.12	16.52	25.93	8.38	0.55	7.82	0.018	6.51
58–150	6.04	13.91	8.53	6.84	0.54	6.92	0.008	3.04
Profile IV								
0–19	13.17	5.86	35.03	12.33	0.52	13.01	0.033	10.63
19–80	26.05	12.73	68.29	27.54	0.45	24.04	0.074	39.34
80–150	28.98	11.39	79.54	29.82	0.37	25.52	0.107	57.08
Profile V								
0–25	26.30	9.30	16.18	9.57	0.62	28.26	0.064	11.07
25–75	16.52	2.84	12.95	7.68	0.50	8.68	0.019	7.31
75–98	13.91	2.46	7.58	6.34	0.55	6.94	0.014	4.39
98–120	12.63	1.73	11.16	10.63	0.41	10.04	0.009	6.50
120–150	17.53	3.97	25.88	13.00	0.52	15.48	0.025	19.73
Profile VI								
0–58	21.38	4.68	23.34	10.42	0.41	18.27	0.036	18.23
58–68	16.54	1.25	10.14	3.46	0.60	7.39	0.010	6.91
68–150	7.69	1.00	15.51	10.59	0.58	27.86	0.021	12.85
Profile VII								
0–13	7.19	4.57	72.98	6.07	1.13	15.97	0.043	6.11
13–43	5.89	6.47	21.41	6.62	1.33	18.16	0.016	11.57
43–64	5.91	12.03	27.52	5.79	1.68	13.41	0.025	10.87
64–80	5.41	8.20	26.20	9.14	0.54	16.31	0.024	12.87
80–150	5.80	4.66	19.02	5.24	0.41	12.12	0.026	10.13

sediments generally increase with decreasing grain size due to the tendency of metals to bind to the finer soil fractions.

In the studied soil profiles, heavy-metal contents were found to vary widely, which is related to the typological diversity of the tested soils, the topography of their location in the field and their physico-chemical properties. The highest metal contents in the soil samples were for zinc, ranging from 7.58 to 79.54 mg·kg^{-1}, and then for nickel, ranging from 3.46 to 29.82 mg·kg^{-1}. Conversely, the lowest concentrations were for mercury, ranging from 0.005 to 0.107 mg·kg^{-1} (Table 4).

Most of the profiles had higher contents of the analysed elements in their upper horizons (Table 5). The humus horizons were characterised by the accumulation of Cr, Hg, Zn and Fe. Analysis of the lead content in soil shows that this element's quantity is positively correlated with the total cadmium content and the share of clay fraction. The average lead content in the study area was half that of the average lead content in samples collected from agricultural areas around the world (Wei and Yang 2010).

The average content of Pb and Zn was identical to the average content indicated by Kabata-Pendias (2011) for Polish soils. The average Cu content was similar to the average copper content reported by Różański et al. (2017) on arable land adjacent to the A1 motorway. The average content of Ni and Cr corresponds to the average content reported by Kabata-Pendias (2011) and that observed by Różański et al. (2017) on arable land adjacent to the A1 motorway. In terms of the vertical distribution of mercury, the same relationship is found as that indicated by Wang et al. (2015), who showed that the concentration of mercury was greatest in the arable layer (0–20), which mainly evidenced the external source of this element in the soil.

Pursuant to the Regulation of the Minister of Environment of 1 September 2016 on methods for assessing pollution of the earth's surface (Journal of Laws No. 2016, item 1395), the total content of trace elements in the studied soils did not exceed the natural content levels (Table 4).

To illustrate the availability of micronutrients in the tested soil, the content of DTPA-extracted forms, which are the

**Table 5** Content of selected bioavailable elements in samples from soil profiles (mg·kg^{-1})

Genetic horizons	Depth (cm)	Cr	Cu	Zn	Ni	Cd	Pb
Profile I							
Ap	0–20	3.88	2.43	2.67	0.36	0.11	0.96
C	20–150	4.46	0.39	1.83	0.41	0.11	0.29
C1	> 150	4.16	0.26	1.97	0.00	0.16	0.13
Profile II							
Ap	0–25	4.58	4.67	11.79	4.16	0.17	0.63
Bw	25–50	0.00	0.85	10.10	7.35	0.00	0.67
C	50–150	2.73	0.53	3.13	0.96	0.00	0.25
Profile III							
Ap	0–35	1.86	1.71	24.03	4.56	0.00	0.30
Bw	35–58	2.43	1.83	11.25	4.02	0.00	0.34
C	58–150	0.89	4.66	7.52	0.80	0.13	0.96
Profile IV							
A	0–19	0.16	1.66	6.16	9.87	0.00	0.30
Bvg	19–80	0.20	2.47	4.14	5.36	0.00	0.34
Cg	80–150	0.00	2.12	34.46	3.87	0.13	0.96
Profile V							
Ap	0–25	0.16	0.15	4.36	3.70	0.1	1.01
A	25–75	0.00	2.62	2.34	1.43	0.00	0.78
Et	75–98	0.33	1.68	2.80	1.10	0.00	0.26
Btg	98–120	0.07	1.71	2.47	1.76	0.09	0.93
Cg	120–150	0.00	3.02	4.66	0.44	0.17	0.05
Profile VI							
Ap	0–58	0.00	0.53	8.80	1.01	0.00	0.31
Bw	58–68	0.05	0.18	3.47	0.45	0.00	0.68
Ck	68–150	0.00	0.62	1.82	0.24	0.00	0.13
Profile VII							
Ap	0–13	0.00	1.18	4.15	2.06	0.00	1.75
A	13–43	0.00	5.84	9.74	0.51	0.17	0.44
Et	43–64	0.17	7.81	3.88	1.09	0.24	4.37
Bt	64–80	0.00	0.85	9.74	1.00	0.42	0.00
C	80–150	0.00	0.63	3.88	0.60	0.20	3.45

Table 6 Enrichment Factor (EF)

	Cr	**Cu**	Zn	Ni	Cd	**Pb**
Mean	0.21	0.13	0.23	0.14	0.1	0.18
Max	3.57	7.51	7.37	2.48	7.64	3.25
Min	1.46	1.58	1.53	1.17	1.76	1.16
SD	0.82	1.62	1.31	0.60	1.57	0.69

Fig. 3 The distribution of metallic elements determined using Enrichment Factor
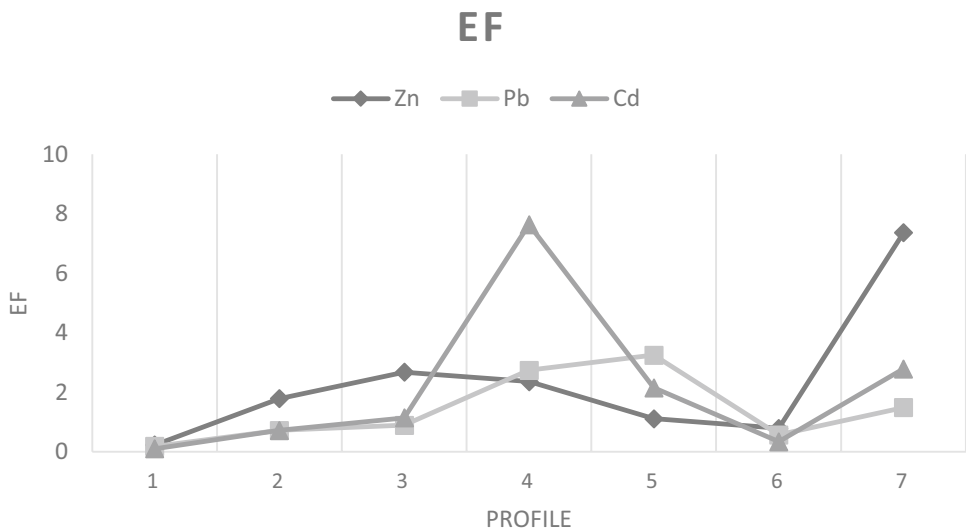
forms defined as bioavailable, was determined. The samples from the soil profiles were highest in bioavailable forms of zinc, ranging from 1.82 to 34.46 mg·kg^{-1} and nickel, ranging from 0.00 to 9.87 mg·kg^{-1} (Table 5). The results were characterised by a high coefficient of variation.

The basic criterion for assessing the ecotoxicological harmfulness of heavy metals is the dissociability of their salts, and the ionic forms are considered mobile, i.e. absorbable by plants. The amounts in which heavy metals are absorbed by plants are strongly influenced by the type and form in which they occur and their total content in the soil. The interaction of the ions of these elements stimulates or inhibits their uptake by plants (Dube et al. 2001; Qishlaqi and Moore 2007).

Statistical analysis showed a statistically significant positive correlation between clay fraction content and total content of: Zn (0.6186775), Ni (0.617177), Pb (0.436323), Hg (0.593812) and Fe (0.482107) at $p < 0.05$. A positive, statistically significant correlation was also found between content of DTPA-extracted Zn (0.530197) and Cd (0.461939)

and share of clay fraction. By contrast, this relationship was negative for Cr DTPA (-0.413060). Organic carbon content was statistically significantly positively correlated with total content of Zn (0.500120), Hg (0.513378) and Ni DTPA (0.573374). The remaining correlations between the examined soil properties and the total content of micronutrients and their bioavailable forms can be considered weak.

The distribution of metallic elements in individual genetic layers of soils was determined using the Enrichment Factor (EF). In most of the studied profiles, EF for Cr, Cu, Zn, Ni, Cd, Pb was in the range 0.5–1.5, which corresponds to the natural levels for these elements. As regards the content of Cd and Pb, levels were slightly elevated in the V profile, and moderately elevated in two genetic layers (Table 6, Fig. 3). This may result from the pedogenetic process of lessivage, but it also may be anthropogenic. In addition, this indicator also showed slightly elevated levels of Cd in profile VII, which are also classified as Luvisols. There is also a slight enrichment in Ni in the luvic (Lat. *eluere*) and argic (Lat.

Table 7 Contamination Factor (CF)

	Cr	**Cu**	Cd	**Hg**	**Ni**	**Pb**	**Zn**
Mean	0.45	0.21	0.29	0.41	0.73	0.45	0.19
Max	2.87	3.45	5.73	1.7	3.23	2.02	7.28
Min	1.20	1.18	1.47	0.97	1.22	0.97	1.24
SD	0.53	0.81	1.11	0.33	0.56	0.39	1.33

Fig. 4 The distribution of metallic elements determined using Contamination Factor
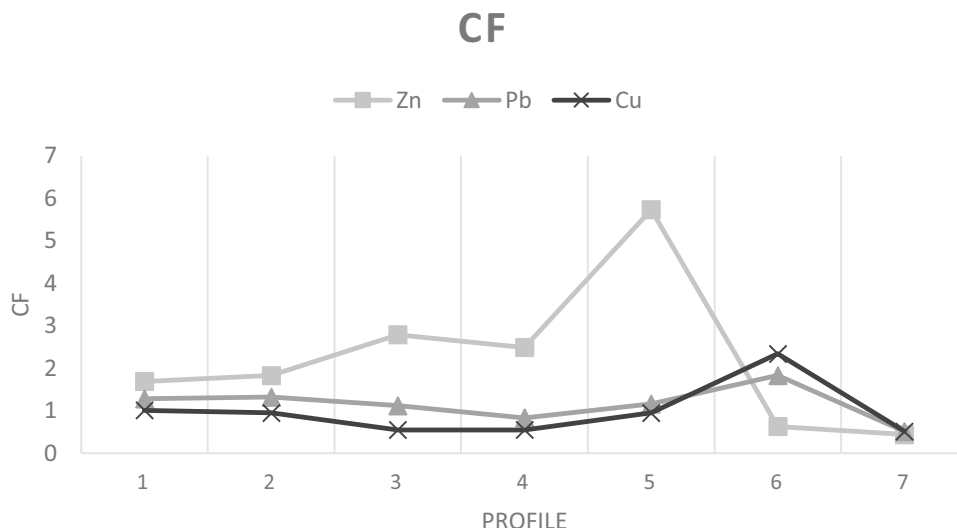
Table 8 Geoaccumulation Index (Igeo)

	Cr	Cu	Zn	Ni	Cd	Pb	Fe
Mean	−0.52	−0.86	−0.70	−0.56	−0.31	−0.53	−3.52
Max	0.28	0.36	0.58	0.04	0.33	0.13	−2.30
Min	−0.13	−0.20	−0.11	−0.22	−0.12	−0.22	−2.86
SD	0.18	0.29	0.29	0.16	0.15	0.18	0.34

argilla) levels in the V profile, which may be associated with the process of lessivage. Profile III, classified as Fluvisols, showed moderate and moderately severe enrichment in copper, which should be considered a result of human impact.

The determined Contamination Factor (CF) indicates low or moderate contamination with metallic elements and thus proves a moderate impact of anthropogenic factors on the soil environment. Only in four cases was CF found to be significant and very high (Table 7, Fig. 4).

The Geoaccumulation Index (Igeo) reflects the degree of soil contamination with metals. Except for a few samples in which values are < 1 (slight to moderate pollution), the Geoaccumulation Index of the soil profiles is negative, evidencing slight contamination of the study area (Table 8, Fig. 5).

Fig. 5 The distribution of metallic elements determined using Geoaccumulation Index
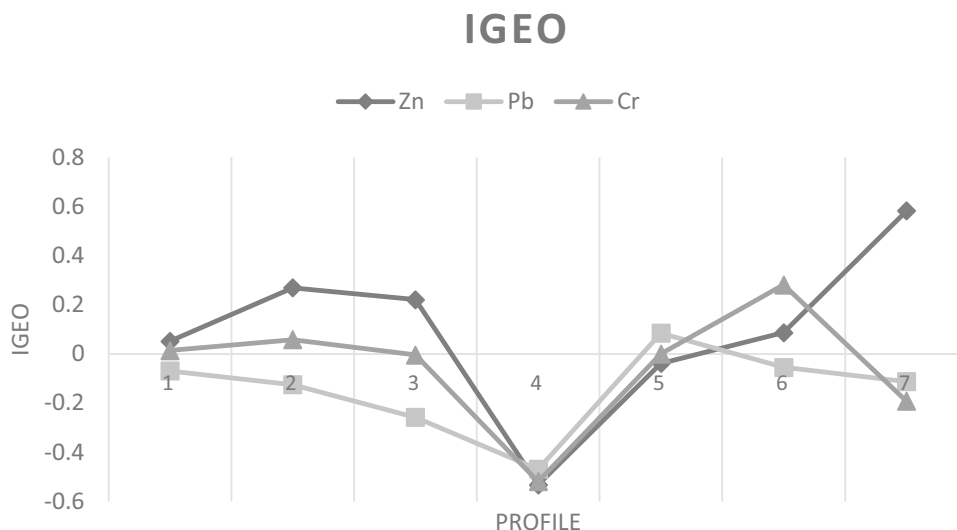
4 Conclusion

The assessment of the human impact on the concentrations and migrations of trace elements in agricultural soil profiles showed variability in the content of heavy metals. This is related to the typological classification, location in the study area and the physical and chemical properties of each tested soil. In all tested soil profiles, the total content of trace elements did not exceed natural levels. There is a noticeable correlation between trace element content and soil granulometry (higher clay fractions were associated with higher levels of micronutrients). The sources of elements in the studied soils were assessed using the following indices: Enrichment Factor (EF), Geoaccumulation Index (Igeo) and Contamination Factor (CF). In most of the profiles, the calculated values of the above indicators were within the ranges of naturally occurring contents of selected elements. Only a few profiles found that the EF values for Cd, Pb and Ni were indicative of human impacts. Similarly, CF and Igeo confirm only minor contamination in the study area. The coefficients of anthropogenic impact on soils indicate that the content of individual elements in the study area was influenced by agriculture, housing and production buildings, but in a moderate range.

Declarations

Conflict of interest The authors declare no competing interests.

References

Ackerman F (1980) A procedure for correcting the grain size effect in heavy metal analyses of estuarine and coastal sediments. Environ Technol Lett 1:518–527

Acosta J A, Martinez- Martinez S, Faz A, Arocena J (2010) Accumulations of major and trace elements in particle size fractions of soils on eight different parent materials. Geoderma 161(1). https://doi.org/10.1016/j.geoderma.2010.12.001

Bednarek R, Prusinkiewicz Z (1999) Soil geography Geografia Gleb, Wydawnictwo Naukowe PWN. Warszawa 47:209

Bednarek R, Dziadowiec H, Pokojska U, Prusinkiewicz Z (2004) Ecological and soil studies Badania ekologiczno-gleboznawcze - Wydawnictwo Naukowe PWN, Warszawa. 344. ISBN 83-01-14216-2

Borrelli P, Robinson DA, Panagos P, Lugato E, Yang JE, Alewell Ch, Wuepper D, Montanarella, Ballabio C (2020) Land use and climate change impacts on global soil erosion by water (2015–2070). Ed. by Erle C. Ellis, University of Maryland, Baltimore County, Baltimore, MD, and accepted by Editorial Board Member Ruth DeFries (36):21994–22001. https://doi.org/10.1073/pnas.2001403117

Callesen I, Raulund-Rasmussen K, Westman CJ, Tau-Strand L (2007) Nitrogen pools and C: N ratios in well-drained Nordic forest soils related to climate and soil texture. Environ Res 12:681–692

Chen S, Guo J (2017) Spatial interpolation techniques: their applications in regionalizing climate-change series and associated accuracy evaluation in Northeast China. Geomat Nat Haz Risk 8(2):689–705

Crock JG, Severson R (1980) Four reference soil and rock samples for measuring element availability in the western energy regions. Geochemical Survey Circular 841:1–16

Czarnowska K, Kozanecka T (2001) Soluble forms of heavy metals in anthropogenic soils from the area of Warsaw. Soil Sci Annu 3/4:45–51

Dromantienė R, Pranckietienė I, Jodaugienė D, Paulauskienė A (2020) The influence of various forms of nitrogen fertilization and meteorological factors on nitrogen compounds in soil under laboratory conditions. Agronomy 10(12):2011. https://doi.org/10.3390/agronomy10122011

Dube JS, Reed JD, Ndlovu L (2001) Proanthocyanidins and other phenolics in Acacia leaves of Southern Africa. Anim Feed Sci Technol 91(1–2):59–67

Drozdowski E (1974) The origin of the Grudziądzki Basin in the light of deposits and glacial forms. Geographical Works 104

Fruzińska R (2011) Accumulation of iron in the soil-plant system in a metal industry area. Civ Environ Eng Rep 7

Gonet S (2007) Protection of organic matter resources. In: The role of organic matter in the environment, (pp. 7–29). PTSH, Wrocław

Håkanson L (1980) An ecological risk index for aquatic pollution control: A Sedimentological Approaching. Water Res 14:975–1001

ISO 10693 (1995) Soil quality - determination of carbonate content - volumetric method

ISO 10694 (1995) Soil quality - determination of organic and total carbon after dry combustion (elementary analysis)

ISO 13320 (2009) Particle size analysis - laser diffraction methods

ISO 10390 (2005) Soil quality — determination of pH

IUSS Working Group WRB (2015)

Jaworska H, Różański Sz, Dąbkowska-Naskręt H (2015) Lead in soils and pine tree bark (Pinus sylvestris L.) from park area exposed to automotive contamination. Environmental Protection and Natural Resources 26(3):12–16. https://doi.org/10.1515/OSZN-2015-001

Kabała C, Karczewska A (2017) Methodology of laboratory analyzes of soils and plants. Wrocław, http://ar.wroc.pl/~kabala. Accessed 10 June 2019

Kabata-Pendias A (2011) Trace elements in soils and plants. Fourth Edition. CRC Press Taylor & Francis Group

Kondracki J (2009) Regional geography of Poland, PWN, 89.

Lindsay WL, Norvell WA (1978) Development of DTPA soil test Zn, Fe, Cu and Mn. Soil Sci Soc Am J 42:421–428

Loring DH, Naes K, Dahle S, Matishow GG, Illin G (1995) Arsenic, trace metals, and organic micro contaminants in sediments from the Pechora Sea, Russia. Mar Geol 128:153–167

Müller G (1969) Index of geoaccumulation in sediments of the Rhine River. Geol J 2:108–118

Naidu R, Biswas B, Willett IR, Cribb J, Kumar Singh B, Nathanail CP, Coulon F, Semple KT, Jones KC, Barclay A, Aitken RJ (2021) Chemical pollution: a growing peril and potential catastrophic risk to humanity. Environ Int 156:106616. https://doi.org/10.1016/j.envint.2021.106616

Niesiobędzka K (2005) Heavy metals in vegetation and soils exposed to anthropopressure. Chem Ecol Eng 12:S4

Okereafor U, Makhatha M, Mekuto L, Uche-Okereafor N, Sebola T, Mavumengwana V (2020) Toxic metal implications on agricultural soils, plants, animals, aquatic life and human health. Int J Environ Res Public Health 17(7):2204. https://doi.org/10.3390/ijerph17072204

Qishlaqi A, Moore F (2007) Statistical analysis of accumulation and sources of heavy metals occurrence in agricultural soils of Khoshk River Banks, Shiraz, Iran American-Eurasian. J Agric Environ Sci 2(5):565–573

Regulation of the Minister of the Environment (2016) Assessment procedures for the land surface pollution. Regulation No. 1395

Różański Sz, Jaworska H, Matuszczak K, Nowak J, Hardy A (2017) Impact of highway traffic and the acoustic screen on the content and spatial distribution of heavy metals in soils. Environ Sci Pollut Res 24:12778–12786

Systematics of Polish soils (2011) PTG, Wrocław- Warszawa 292

Trawczyński C (2016) The yield and tuber quality of new potato cultivars under conditions of varied mineral nitrogen fertilization. Acta Agroph 23(2):261–273

Uziak S, Klimowicz Z (2000) Elements of soil geography and soil science. UMCS Lublin

Wang Q, Zhang, Xin X, Zhao B, Ma D, Zhang H (2015) The accumulati on and transfer of arsenic and mercury in the soil under a long-term ferti lizati on treatment. J Soils Sediments 16(2):427–437

Wei B, Yang L (2010) A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. Microchem J 94:99–107

World Reference Base for Soil Resources (WRB 2016)

Zhang J, Liu CL (2002) Riverine composition and estuarine geochemistry of particulate metals in China – weathering features anthropogenic impact and chemical fluxes. Estuar Coast Shelf Sci 54(6):1051–1070