ARE SOILS FORMING ON BUILDINGS INDICATORS OF POLLUTION IN THE CITY? A CASE STUDY FROM LUBLIN (EASTERN POLAND)

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Abstract: The aim of the study was to determine the suitability of building-forming soils (edifisols) for assessing the pollution of urban areas, using a medium-sized city in Poland E as an example. The research hypothesis was that these soils, due to their specificity and occurrence, could be indicators of environmental degradation, with a particular focus on elevated trace element contents resulting from intensive anthropopression in urbanised areas. Eight soil profiles were selected, of which 14 soil samples were taken. The samples were taken from buildings of different ages and uses. Selected soil properties were then determined: particle size distribution, pH, organic carbon (OC), $CaCO_3$, hydrolytic acidity (HA) and base exchange capacity (BEC) values, the effective cation exchange capacity (ECEC) and base saturation (BS). Metals present in high concentrations included Cd, Ni, Cu, Cr and Zn. Based on calculation of selected geochemical indices such as enrichment factor (EF), geoaccumulation index (I_{geo}), pollutant load index (PLI) and ecological risk index (RI), it was found that the investigated soils, characterised by elevated content of heavy metals of anthropogenic origin, can be considered as indicators of environmental pollution. The geochemical indices used in this study allowed us to demonstrate that the investigated soils are characterised by an elevated content of heavy metals of anthropogenic origin, and that soils formed on buildings can be indicators of the environment. The use of edifisols as indicators of pollution could make a significant contribution for a better assessment of the city's ecosystem in the future.

Keywords: anthropopression, heavy metals, technosols, edifisols, urban soil, Lublin

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Introduction

Soils are an important and complex component of the urban ecosystem, and their original character is constantly being transformed (Blum 1998, Zhang et al. 2003b, Pickett, Cadenasso 2009, Greinert 2015). One form of negative impact on soil, particularly in urban areas, is the accumulation of heavy metals (HMs) in soils (Alloway 2013, Yang, Zhang 2015, Plak 2018, El-Sherbiny 2019, Wieczorek et al. 2020). The source of this phenomenon is primarily human activity related to industrial production, transport and agriculture (Alloway, Ayres 1999, Wang et al. 2005). Due to their mobility and tendency to bioaccumulate, trace elements not only affect soil quality and function, but can also pose a serious threat to human health (Cabral-Pinto et al. 2018, Pratush

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et al. 2018, Gruszecka-Kosowska et al. 2020). This is a global problem. Despite the fact that urban areas account for only about 0.69% of the land area (Zhao et al. 2021), cities are inhabited by more than 4.3 billion people or nearly 55% of the population (UN 2019).

Analysis of the total trace element content of soil can contribute to determining the geochemical background (GB) value, but is not a sufficient method for assessing environmental quality (Hong-gui et al. 2012, Kowalska et al. 2018). The key to a comprehensive assessment of the state of the environment is the use of appropriate pollution indicators. These indicators make it possible to estimate the environmental risk associated with the deposition of toxic substances and to determine whether their accumulation has occurred as a result of anthropogenic processes (Mazurek et al. 2017, Maurya et al. 2020). Contamination indicators are of great importance for monitoring soil quality and health, so their use is particularly valid for urban soils (Plak 2018).

A specific type of soil found in urbanised areas is the soil that forms unintentionally on man-made structures. These soils are defined in the latest Polish Soil Classification (2019) as edifisols (Latin: *aedificum* – building). They are shallow soils (up to 30 cm thick) that form on buildings or their structural elements as a result of the accumulation of wind-transported material, such as ‘street dust’, and dust from neighbouring soils and the death of organisms living there (Kantor et al. 2018, Gülşen, Tokalıoğlu 2016). Edifisols are also formed as a result of *in situ* weathering of building material (bricks, concrete, mortar) or the soaking of material from higher sections of buildings. The closest counterparts to the studied soils in The World Reference Base (2022) systematics are the Isolatic Linic Technosols.

So far, only a few studies on edifisols have been published. Charzyński et al. (2011) and Charzyński and Hulisz (2013) conducted a preliminary study of soils formed on buildings in Toruń (N Poland) and introduced the term edifisols. Charzyński et al. (2015) described the properties of edifisols in selected countries in Europe and Africa, while Markiewicz et al. (2018) undertook a study to characterise the organic matter of edifisols in Poland and Romania. Kabała et al. (2020) presented an overview of technogenic soils according to the Polish Soil Classification, which also included a description and the main characteristics of edifisols.

Edifisols can provide an excellent object for studying the environmental state of urbanised areas. They are formed on objects constructed by man, but without his conscious participation, hence the specific nature of their genesis. They reflect the state of the local environment because they are relatively young formations, and since the beginning of their formation, they record and archive any changes in their surroundings. The complexity of the functioning of edifisols in urban areas and their interaction with human activities is not yet fully understood and knowledge is still insufficient. In urban areas, the technogenic properties of the substrate and degrading external factors need to be considered to determine the degree of anthropopression and the resistance of these soils to degradation. At the same time, edifisols can be a good indicator of the state of the environment, as well as provide habitat functions for plants (Charzyński et al. 2013, Charzyński et al. 2015, Plak 2018). Edifisols are complex and dynamic systems that are built by natural and anthropogenic processes.

The aim of this study is to use edifisols as pedoindicators of the environment quality, by investigating the content of selected pollutants, which are HMs, and determining geochemical indices: geochemical index (I_{geo}), enrichment factor (EF), pollutant load index (PLI) and ecological risk index (RI). At the same time, the study will cover the functioning of these soils in the urban ecosystem based on basic properties (grain size composition, reaction, sorption properties, organic carbon [OC] content). Understanding the conditions of occurrence and the properties of edifisols can be used to monitor and assess the pollution status of urban areas, considering the health risk of its inhabitants.

Materials and methods

Study area and soil sampling

The study was conducted between 2020 and 2023 in Lublin. It is the largest city in eastern Poland (147.5 km^2), with a population of approximately 332,000 (status for 2022). The average population density for the city is 2252 people per square kilometre, which is several times higher than the Polish average of 122 people per square kilometre. Built-up areas: residential, commercial, industrial, as well as roads and tracks cover 34.8% of the city's area. Urban green areas account for 30.8%, of which forests account for 14.2% and water accounts for 2.4%, making Lublin one of the greenest cities in Poland. The remaining 32.0% is developed for arable land. The varied relief of the western part of Lublin is related to the occurrence of loess cover (there are numerous gullies and dry valleys), while the more monotonous eastern part is made up of gneisses, marls and gaizes, covered by a thin layer of eluvial and deluvial sediments (Superson et al. 2018, Dobrowolski, Chabudziński 2021). Lublin is located in a temperate climate zone, with an average multi-year air temperature of 8.1°C and an average multi-year precipitation of 551 mm (Kaszewski 2008). The western part of the city is dominated by loess loam soils in a complex with brown soils, while on the eastern side there are podzols and rusty soils formed mainly from sandy formations, brown soils and, in places, black earths. In the river valleys, chernozemic muds, proper muds and peat silt soils have developed (Plak 2007, 2018).

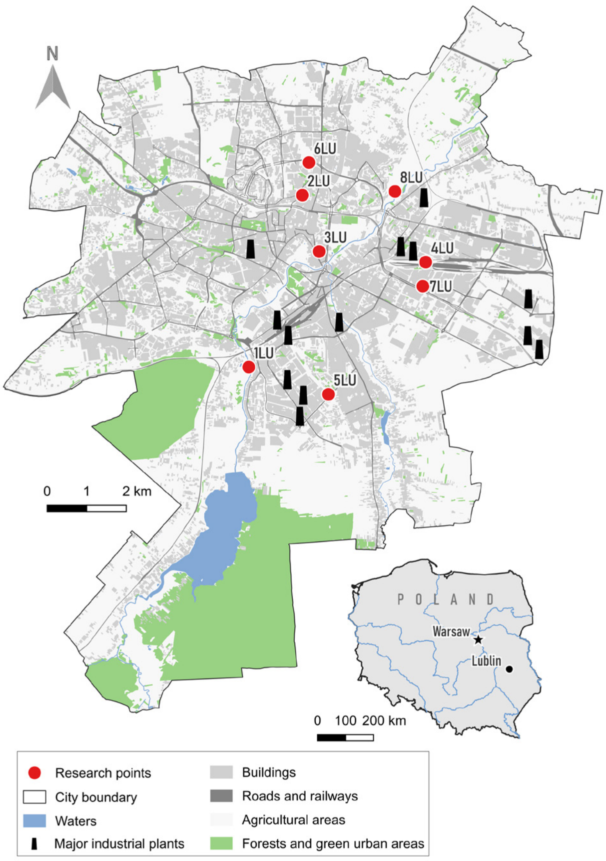

Fig. 1. Location of study area.

The first stage of the work was to carry out a field reconnaissance with the aim of finding abandoned or neglected buildings on which the soils under study could potentially occur. A useful indicator of such sites was the presence of vegetation overgrowing fragments of roofs and gutters. Subsequently, eight soil profiles, of which 14 soil samples were taken, were examined at the selected sites (Fig. 1). The following building elements were sampled: brick walls (five samples), cracks and fissures present in concrete structural elements (two samples), gutters on buildings (five samples) and bridge foundations (two samples). The dominant vegetation at the sampling locations is also described (Table 1). The location of the points was determined using a GPS receiver.

Laboratory analysis

All samples were air-dried and sieved through a 2-mm sieve. The soil material was then subjected to standard physical and chemical analyses as follows:

- Grain size composition was determined using the aerometric-sieve method (Sheldrick and Wang 1993).
- Soil reaction (pH) was determined by potentiometric method in H_2O at a ratio of 1:5 (PN-ISO 10390:1997).
- OC content was determined by sulpho-chromic oxidation (PN-ISO 14235:2003).
- $CaCO_3$ was determined by the Scheibler method (PN-ISO 10693:2002).
- The extraction of basic cations was performed using 1 M ammonium acetate based on the principles of the ammonium acetate method The International Soil Reference and Information Centre–Food and Agriculture Organization of the United Nations (Van Reeuwijk 2002). In the percolate obtained after extraction with 1 M ammonium acetate, Ca, Mg, Na and K were determined using the Flame Atomic Absorption Spectrometry (FAAS) method. The sum of the contents (Ca + Mg + Na + K) provided the base exchange capacity (BEC). Exchangeable acidity (HA) was determined in 1 M KCl percolate after extraction using method no. 11 by ISRIC-FAO (Van Reeuwijk 2002).

Table 1. General characteristics of the study sites.

Profile	Location	Type of building	Position			Technogenic parent material	Existing vegetation
			Fragment of the building	Height above ground level [m]	City district		
1LU	51.216N 22.544E	Watermill*	Brick wall	4	Residential	Brick, mortar	*Geum urbanum* L.
2LU	51.255N 22.565E	Wall*	Brick wall	1	Residential	Brick, mortar	*Acer negundo* L.
3LU	51.243N 22.570E	Industrial plant (dyework)*	Brick wall	3.5	Residential	Brick, mortar	*Calamagrostis epigejos* L. *Solidago canadensis* L.
4LU	51.239N 22.608E	Railway outbuilding*	Gap in concrete ceiling	2.5	Industrial	Concrete	*Solidago canadensis* L. *Poa annua* L.
5LU	51.211N 20.570E	Industrial plant	Gutter	4	Industrial	n.d.	*Poa pratensis* L.
6LU	51.263N 22.568E	Car garage	Gutter	3	Residential	n.d.	*Alliaria petiolata*
7LU	51.234N 22.607E	Railway ramp next to an industrial plant*	Concrete railway ramp	1	Industrial	Concrete	*Calamagrostis epigejos* L. *Solidago canadensis* L.
8LU	51.255N 22.599E	Road bridge*	Concrete bridge pillar	1	Industrial	Concrete	*Solidago canadensis* L. *Acer tataricum* L.

* building abandoned or in a state of disrepair.
n.d. – not determined.

Effective cation exchange capacity (ECEC) was calculated by summing BEC and HA. Base saturation (BS) was calculated as BEC's share of ECEC expressed as a percentage.

– The content of pseudototal HMs (Cd, Cu, Mn, Pb, Zn, Ni, Cr, Fe) was determined using the method of Flame Atomic Absorption Spectrometry after soil mineralisation with aqua regia (PN-ISO 11466:2002).

Analyses of HMs content were carried out in triplicate. Arithmetic averages of the results are presented in the paper. Correctness of HMs determination were carried out based on reference samples of soils SO-2 and SO-4 from Canada Centre for Mineral and Energy Technology. Precision of analyses was within the range from about 1.9% to about 8% (e.g. 1.92% for Cu, 2.02% for Cd, 2.43% for Pb, 3.04% for Zn, 7.4% for Cr and 8.1% for Ni) Detection limits for F-AAS are 1.5 $\mu g \cdot dm^{-3}$ for Cd, 3 $\mu g \cdot dm^{-3}$ for Cu, 6 $\mu g \cdot dm^{-3}$ for Cr, 10 $\mu g \cdot dm^{-3}$ for Ni and Pb and 1 $\mu g \cdot dm^{-3}$ for Zn.

Statistical analyses

The results obtained were statistically analysed. Minimum and maximum values, arithmetic means, standard deviation (SD) and coefficient of variation (CV) were determined. The Pearson correlation coefficient ($p < 0.05$) was used to determine the relationship between the analysed HMs and selected properties of the studied soils.

Cluster analysis (CA) is a method for geometrically multidimensional clustering of data. Depending on the method used, data can be clustered based on, among other things, geometric shortest distance, variance, mean, centre of gravity, etc. We used Warde's method, which considers the variance within a group. This method gives the clearest results. The data for clustering have been normalised. This is a statistical method that allows the significance of each type of data to be equalised (e.g. metals whose natural content is very high with those whose content is low).

Principal component analysis (PCA) allows the number of variables describing an object (in our case, a sampling site) to be reduced to a smaller number of variables: principal components. Each new principal component depends on one or more core variables. The highest values are taken by those variables that influence the principal component to the highest level. At the same time, these principal variables are most strongly correlated with each other. This means that PCA can be used as a method to group data according to their variability. It also means that the variables most strongly influencing a given principal component can have similar origins.

Pollution indices

The degree of HMs contamination of the investigated soils was described using the following geochemical indices: geoaccumulation index (I_{geo}), EF, PLI and potential ecological risk index (RI).

The I_{geo}, developed by Muller (1969), is used to assess HMs contamination based on its content in the soil material under study in relation to a specific GB. The I_{geo} is calculated according to the formula:

$$I_{geo} = \log_2 \left[\frac{C_n}{1.5 \cdot \mathrm{GB}}\right]$$

where:
- C_n – concentration of individual HMs in the sample,
- GB – geochemical background value for the element under consideration,
- 1.5 – a constant value, reflecting natural variations in the content of the element concerned in the environment.

The I_{geo} covers seven environmental quality classes:
- $I_{geo} \leq 0$: unpolluted
- $0 < I_{geo} < 1$: unpolluted–moderately polluted
- $1 < I_{geo} < 2$: moderately polluted,
- $2 < I_{geo} < 3$: moderately–highly polluted,
- $3 < I_{geo} < 4$: highly polluted,
- $4 < I_{geo} < 5$: highly–extremely pollute,
- $I_{geo} \geq 5$: extremely polluted.

The EF is an indicator of the possible influence of anthropopressure on the concentration of HMs in the soil. It is based on a comparison of the content of the element analysed against the concentration of a reference element, that is, one that is particularly stable in the soil and does not actively participate in biogeochemical cycles (Sutherland 2000, Plak 2018). Reference elements are most commonly Fe, Al, Mn and Rb. EF is determined according to the formula:

$$\mathrm{EF} = \frac{C_n / \mathrm{GB}_n}{C_{\mathrm{ref}} / \mathrm{GB}_{\mathrm{ref}}}$$

where:
- C_n – concentration of the analysed element in the sample,
- GB_n – geochemical background of the element analysed,
- C_{ref} – concentration of the reference element in the sample,
- $\mathrm{GB}_{\mathrm{ref}}$ – geochemical background of the reference element.

Based on the EF, the following categories of enrichment can be distinguished (Acosta et al. 2011):
- EF <2 – minimal enrichment,
- EF 2–5 – moderate enrichment,
- EF 5–20 – significant enrichment,
- EF 20–40 – very hight enrichment,
- EF >40 – extreme enrichment.

Soil contamination can also be assessed using the pollution load index (PLI). It allows the magnitude of contamination in soils to be expressed as an integrated load of all HMs or other toxic elements analysed. PLI values below 1 indicate the absence of contamination, while values above or equal to 1 indicate the presence of contamination (Tomlinson et al. 1980). PLI is calculated as

$$\mathrm{PLI} = \sqrt[n]{\mathrm{CF2} \cdot \mathrm{CF2} \cdot \mathrm{CF3} \cdot ... \cdot \mathrm{CF}_n},$$

where:
- n – amount of HMs and
- CF – contamination factor.

$$\mathrm{CF} = \frac{C_n}{\mathrm{GB}}$$

where:
- C_n – concentration of the analysed element in the sample,
- GB – geochemical background of the element analysed.

PLI values below 1 indicate the absence of contamination, while values above or equal to 1 indicate the presence of contamination.

The study also uses an ecological RI to assess the degree of ecological risk caused by HMs concentrations in water, air and soil (Håkanson 1980). The index is calculated according to the following formula:

$$\mathrm{RI} = \sum_{i=1}^{n} Er_i$$

where:
- n – amount of HMs,
- Er_i – a single environmental risk factor index calculated from the equation:

$$Er_i = T_i \cdot \frac{C_i}{\mathrm{GB}}$$

where T_i is the toxic response factor of a single metal. Håkanson (1980) gave the following values for this ratio: Cd – 30, Cr – 2, Cu – 5, Ni – 5, Pb – 5 and Zn – 1. There are five categories of pollution: low (<40), moderate (Er_i = 40−80), significant (Er_i = 80−160), high (Er_i = 160−320) and very high (>320).

Potential ecological RI is defined as the sum of the ecological RI for metals in a given sample (Soliman et al. 2015). There are four categories of index (Håkanson 1980): RI <150 − low, RI 150–300 − moderate, RI 300–600 − considerable and RI >600 − high.

Based on the determined contents of the pollutants studied, indicators commonly used in the literature were calculated to determine the degree of environmental pollution and the associated risks. At the same time, an extremely important element when considering the level of soil contamination in urbanised areas is the determination of GB. The primary purpose of determining this parameter is to distinguish concentrations that are so-called natural from concentrations that deviate from natural, that is, anthropogenic. Most studies of soils located in areas with different functions and anthropopressures use the GB values determined by Pasieczna (2003) to assess the degree of their HMs contamination. The variability of GB of Polish soils is mainly due to the variable chemical composition of the parent rocks on which these soils were formed. In the case of the studied soils, these regularities do not occur due to the specific soil-forming process on anthropogenic soil. For edifisols, the local GB values for Lublin determined by Plak (2018) were used (Table 4). To assess the degree of HMs contamination, the local GB was determined based on the analysis of the average HMs content from the C horizons of the bedrock in the replicate profiles of soils located in Lublin. The methodology used for soil extraction and determination of HMs for edifisols and for GB were the same. Against this background, a number of regional or local anomalies of geological or anthropogenic origin may be identified (Gałuszka 2007).

In the case of the studied soils, these regularities do not occur due to the specific soil-forming process on anthropogenic ground, hence this approach was followed by the authors for the issue. As the investigated soils are characterised by a small thickness (maximum 12 cm), pollution indices were calculated for the whole profiles from the average HMs content in the individual levels.

Results and discussion

Soil morphology

The investigated soils were formed on buildings with different histories and purposes (Fig. 2). They were characterised by low thickness (up to a maximum of 12 cm) and the presence of a relatively large number of artefacts in the profile. The morphology was mostly characterised by one or two genetic horizons, with only the 6LU profile delineating three genetic horizons. The typical sequence of soil horizons is: Au(h)-Cu(Au2). Regardless of the location and type of technogenic parent material, the dominant soil species is sandy loam or loamy sand (USDA 2002). This material is derived from weathering mortar that is technogenic parent material for edifisols, or it is the material transported by wind and rainwater.

A characteristic feature of soils of this type is the content of artefacts, which in the case of edifisols in Lublin reached up to 20% (vol.). These are mainly rubbish and various types of waste delivered to the soil by man and avifauna (Fig. 3).

Among the artefacts present in the edifisols formed in the gutters, bituminous substances (roofing felt) and glass shards predominated.

Fig. 2. Analysed soils: 1LU – watermill, 2LU – brick wall, 3LU – industrial plant (dyehouse), 4LU – railway outbuilding, 5LU – industrial plant, 6LU – car garage, 7LU – railway ramp, 8LU – concrete bridge pillar.

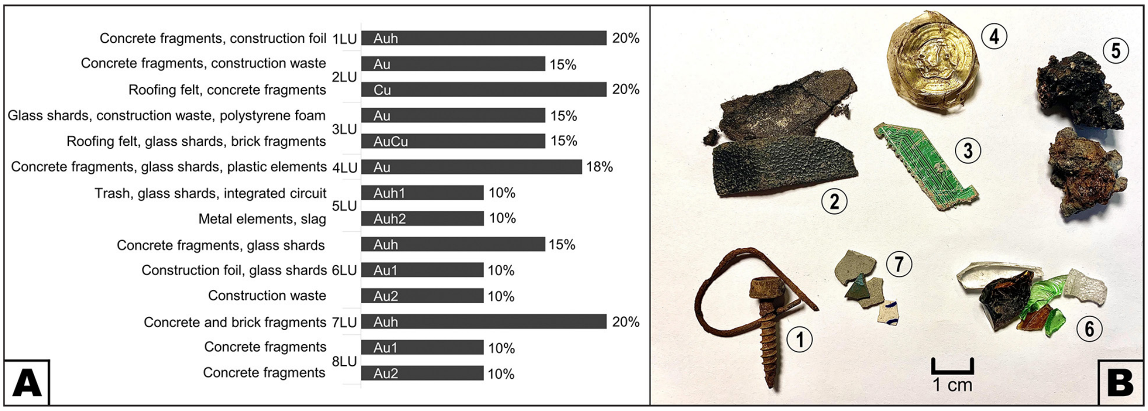

Fig. 3. A) Type of artefacts and the percentage of edifisols in them (% vol.). B) Examples of artefacts in edifisols: 1 – metal components, 2 – roofing felt, 3 – integrated circuit, 4 – trash (bottle stoper), 5 – slag, 6 – glass shards, 7 – plastic elements.

A large group of artefacts consisted of elements of building materials such as polystyrene and building foil, as well as fragmented technogenic parent material (Fig. 3).

Grain size composition and chemical properties

The texture determines the course of various physicochemical and biological processes and also influences soil structure and the development of the plant cover (Bednarek et al. 2004). The soils studied were mainly characterised by the sand grain size. The average sand content was 64.1%, while the silt content was 34.8% and the clay fraction averaged 1.1% (Table 2). Edifisols formed on masonry and concrete elements were characterised by a high content of skeletal parts (>2 mm). The pH (in H_2O) value of the tested soils ranged from 7.1 to 8.2 (Table 3). The reaction of soil samples taken from masonry and concrete structural elements was mainly alkaline, which is closely related to the presence of mortar, of which lime is a component. The reaction of the soils formed in the gutters was mostly neutral. The percentage of $CaCO_3$ reached up to 12.4, and the percentage of OC varied considerably among the samples. The highest percentage of OC (8.0%) was found in the soil formed on the water mill ruins (profile 1LU), while the lowest (0.3%) was recorded in profile 3LU.

Cation exchange properties

ECEC is a very important and frequently used indicator in soil quality assessment. It depends on the reaction, humus content and type, grain size and bedrock, as well as on the use. The soils studied were characterised by a relatively high cation exchange capacity: from 5.41 to 109.20 cmol · kg^{-1}, with the proportion of base cations in the sorption complex (BS) ranging between 65.36% and 98.93% (Table 3). In general, higher sorption capacity values were recorded in the subsurface horizons and in soils formed on walls.

Significantly lower sorption capacity (ECEC) values occurred in profiles located in roof gutters (profile 5LU and 6LU). The saturation of the sorption complex with alkaline cations in these profiles was also the lowest, ranging from 65.63% to 87.88%. The sorption complex of the analysed soils is saturated mainly with Ca^{2+} cations, which represent up to 95.54% of the sorption complex (profile 8LU).

HMs content and geochemical indicators

In the soil profiles studied, there was a large variation in the content of HMs (Table 4), which is mainly related to their properties, specific location and the impact of the city. The calculated CVs for individual metals were: Cd – 62%, Ni – 86%, Cu – 56%, Zn – 82%, Cr – 45%, Mn – 65%, Pb – 191% and Fe – 65%. The higher the CV value, the greater the anthropogenic influence (Martin et al. 2006).

Analysis of HMs content following aqua regia extraction indicated that profile 8LU was most contaminated with Pb and Cd, with average lead concentrations measuring 617.7 mg · kg^{-1} (range: 475.8–759 mg · kg^{-1}) and cadmium measuring 6.0 mg · kg^{-1} (range: 6.0–6.1 mg · kg^{-1}) (Table 4). The

Table 2. Granulometric composition and chemical properties of the studied soils.

Horizon	Depth	Skeleton	Fraction			Soil texture (USDA)	pH [H_2O]	OC	$CaCO_3$
			Sand (2.0–0.05 mm)	Silt (0.05–0.002 mm)	Clay (<0.002 mm)				
	[cm]	[%]				[–]		[%]	
1LU Isolatic Linic Technosol – brick wall (watermill)									
Auh	0–6	54.9	43.6	51.4	5.0	SiL	7.1	8.0	2.1
2LU Isolatic Linic Technosol – brick wall									
Au	0–3	42.9	51.4	46.1	2.5	SL	7.8	1.2	5.6
Cu	3–6	5.1	64.6	32.9	2.5	SL	8.1	0.5	6.8
3LU Isolatic Linic Technosol – brick wall (dyework)									
Au	0–7	37.6	81.3	16.2	2.5	LS	8.0	1.5	12.4
AuCu	7–10	20.0	81.8	15.7	2.5	LS	8.2	0.3	6.8
4LU Isolatic Linic Technosol – roof of outbuilding (gap)									
Au	0–5	26.6	70.4	29.6	0.0	LS	7.9	3.5	2.8
5LU Isolatic Linic Technosol – gutter on an industrial plant									
Auh1	0–4	0.0	67.4	32.6	0.0	SL	7.7	6.8	n.d.
Auh2	4–8	0.0	62.3	37.7	0.0	SL	7.4	6.5	n.d.
6LU Isolatic Linic Technosol – gutter on a car garage									
Auh	0–4	0.0	60.5	39.5	0.0	SL	7.3	5.5	n.d.
Au1	4–8	0.0	64.1	35.9	0.0	SL	7.7	3.8	n.d.
Au2	8–10	0.0	43.5	56.5	0.0	SiL	7.2	3.8	n.d.
7LU Isolatic Linic Technosol – concrete railway ramp									
Auh	0–6	44.9	62.6	37.4	0.0	SL	7.8	5.2	3.3
8LU Isolatic Linic Technosol – concrete bridge pillar									
Au1	0–6	19.5	73.0	27.0	0.0	LS	7.7	2.2	1.5
Au2	6–12	20.4	71.3	28.7	0.0	LS	7.8	2.8	2.2

n.d. – not determined.

Table 3. Cation exchange properties.

Horizon	Depth	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HA	BEC	ECEC	BS
	[cm]	[cmol · kg^{-1}]							[%]
1LU Isolatic Linic Technosol – brick wall (watermill)									
Ada	0–6	73.00	11.02	1.65	0.96	5.10	86.63	91.73	94.44
2LU Isolatic Linic Technosol – brick wall									
Aca	0–3	65.80	6.75	1.98	0.61	1.65	75.14	76.79	97.85
Ca	3–6	90.80	5.00	1.08	0.49	1.25	97.37	98.62	98.74
3LU Isolatic Linic Technosol – brick wall (dyework)									
Aa	0–7	88.20	3.69	1.72	0.38	1.02	93.99	95.01	98.93
AC(Ca)	7–10	104.00	1.94	1.60	0.28	1.38	107.82	109.20	98.74
4LU Isolatic Linic Technosol – roof of outbuilding (gap)									
Ada	0–5	33.76	0.02	0.14	1.02	0.96	34.95	35.91	97.33
5LU Isolatic Linic Technosol – gutter on an industrial plant									
A	0–4	4.35	0.02	0.10	0.09	2.04	4.56	6.60	69.10
Ada	4–8	7.39	0.01	0.12	0.11	1.53	7.63	9.16	83.29
6LU Isolatic Linic Technosol – gutter on a car garage									
Ada	0–4	6.34	0.01	0.11	0.23	1.74	6.68	8.42	79.34
Aca	4–8	3.33	0.01	0.10	0.09	1.88	3.54	5.41	65.36
Ca	8–10	8.67	0.01	0.10	0.13	1.23	8.92	10.15	87.88
7LU Isolatic Linic Technosol – concrete railway ramp									
Ada	0–6	23.37	0.01	0.14	0.05	0.89	23.58	24.46	96.38
8LU Isolatic Linic Technosol – concrete bridge pillar									
A	0–6	17.79	0.01	0.11	0.35	1.20	18.26	19.46	93.83
Ada	6–10	21.18	0.01	0.13	0.37	0.86	21.68	22.54	96.21

concentrations of other analysed HMs were also increased compared to other profiles. The contamination of this profile with HMs may be attributed to the use of corrosion protection preparations in viaduct structure maintenance. Profiles 1LU, 2LU and 3LU exhibited the lowest HMs contamination following aqua regia extraction and developed on brick walls. For instance, the average Cu content in these three profiles was 9.7 mg · kg^{-1} (range: 2.9–16.2 mg · kg^{-1}) and the Zn content was 121.1 mg · kg^{-1} (range: 24.5–257.3 mg · kg^{-1}), with lead content found to be below the detection limit. Another distinct group of edaphic profiles comprised those formed in gutters. In profiles 5LU and 6LU, the average Zn concentrations were 553.3 mg · kg^{-1} (range: 436.6–670.0 mg · kg^{-1}) and 738.5 mg · kg^{-1} (range: 340.4–1177.0 mg · kg^{-1}), respectively, while the average Cr concentrations were 88.0 mg · kg^{-1} (range: 80.2–95.8 mg · kg^{-1}) and 45.5 mg · kg^{-1} (range: 43.9–47.4 mg · kg^{-1}), respectively. Elevated concentrations of these two elements may be linked to their release due to substrate degradation.

The Pb, Zn and Cu contents of the soils studied were similar to the values reported by Charzyński et al. (2015) in soils of this type in different parts of Europe and Africa. However, the mean HMs contents of the edifisols were significantly higher than the mean HMs contents indicated by Plak (2018) for the soils of Lublin; the mean Zn content was five times higher, while Ni content was more than two and a half times higher. The average Cu and Zn contents were also higher than the average values for Polish soils reported by Kabata-Pendias and Pendias (1993).

The HMs content of edifisols was compared with the HMs content of street dust in Lublin, as reported by Zgłobicki et al. (2018). The results showed no correlation, indicating that road dust is not a source of HMs enrichment in edifisols.

Table 4. Heavy metal content.

Horizon	Depth	Cd	Cu	Mn	Pb	Zn	Ni	Cr	Fe
	[cm]	[mg · kg^{-1}]							[g · kg^{-1}]
1LU Isolatic Linic Technosol – brick wall (watermill)									
Ada	0–6	2.2	16.2	181.8	n.d.	257.3	n.d.	43.0	8.8
2LU Isolatic Linic Technosol – brick wall									
Aca	0–3	1.8	9.6	150.2	n.d.	77.3	n.d.	39.6	6.5
Ca	3–6	2.0	6.2	125.9	n.d.	26.3	n.d.	36.5	5.2
3LU Isolatic Linic Technosol – brick wall (dyework)									
Aa	0–7	2.7	13.5	158.6	n.d.	220.1	n.d.	29.8	4.8
AC(Ca)	7–10	1.6	2.9	72.8	n.d.	24.5	n.d.	21.0	2.5
4LU Isolatic Linic Technosol – roof of outbuilding (gap)									
Ada	0–5	1.2	29.4	292.5	16.2	150.6	29.1	27.6	14.1
5LU Isolatic Linic Technosol – gutter on an industrial plant									
A	0–4	1.6	45.6	794.8	34.5	670.0	60.9	95.8	39.0
Ada	4–8	1.5	44.8	744.1	30.5	436.6	53.1	80.2	36.4
6LU Isolatic Linic Technosol – gutter on a car garage									
Ada	0–4	1.2	34.0	758.6	21.1	340.4	38.8	43.9	25.8
ACa	4–8	1.6	41.0	449.6	45.0	698.1	38.8	47.4	28.7
Ca	8–10	2.2	52.0	355.0	80.6	1177.0	51.7	45.3	34.9
7LU Isolatic Linic Technosol – concrete railway ramp									
Ada	0–6	3.3	34.8	457.7	116.9	432.6	39.3	42.2	22.4
8LU Isolatic Linic Technosol – concrete bridge pillar									
A	0–6	6.0	55.2	258.6	759.6	359.7	21.5	31.2	14.8
Ada	6–12	6.1	33.9	310.0	475.8	275.4	20.3	28.0	15.6
mean		2.5	29.9	365.0	112.9	367.6	25.2	43.7	18.5
standard deviation		1.6	16.8	236.6	215.5	301.6	21.6	19.8	12.2
kurtosis		0.3	0.1	0.2	0.5	0.3	0.1	0.3	0.1
skewness		82.2	−12948.0	131032176.9	308047370.4	474593294.9	12534.4	165749.3	8191.8
Local geochemical background		0.5	3.0	120.0	10.0	25.0	3.0	3.0	9200.0
		[mg · kg^{-1}]							

n.d. – not determined.

The HMs content determined in the tested samples did not exceed the permissible levels specified in the regulations of the Ministry of the Environment in most cases (Journal of Laws No. 2016, item 1395). The permissible limits were slightly exceeded in some levels of the studied soils for Cd. In the 6LU profile produced in the trough, the permissible contents of Zn were exceeded, and for Cd, the level exceeded even twice the permissible content.

The analysis of correlation coefficients calculated for the contents of artefacts, ECEC, HMs and OC revealed significant correlations between Fe and OC, as well as between Ni and Zn. In addition, a strong positive correlation was observed among Ni, Cu and Mn. The highest correlation was found between Pb and Cd, with a correlation coefficient of r = 0.92. Many authors of studies on urban soil contamination indicate that the distribution of HMs depends primarily on the type of anthropogenic activity, which determines both the quantitative and qualitative aspects of the pollutants present in soils. These regularities are mainly marked in industrial cities and agglomerations, where the different functional zones are clearly separated (Horváth et al. 2015, Li et al. 2013, Mireles et al. 2013, Wang et al. 2007).

Based on PCA, two main groups of elemental origin can be distinguished: natural and anthropogenic (Fig. 4). The group of elements with a natural origin can include Cr, Mn, Ni and Zn. The second group consists of Pb and Cd, whose supply to the soil is of anthropogenic origin. Cu can be included in a separate group, and the genesis of this element in edifisols can be mixed. These are surprising results, especially since in other soil types (e.g. Szuszkiewicz et al. 2016), Pb was always a metal indicative of anthropopressure. Pb in the investigated soils significantly exceeded background, especially in profiles 7LU and 8LU.

CA analysis yielded a dendrogram grouping variables with similar multidimensional characteristics into the same cluster. According to the diagram, two distinctive groups can be distinguished. The first includes the edifices taken from profiles 1LU, 2LU and 3LU. These are profiles developed on the masonry because of brick and mortar weathering. The second group includes edifisols from the other locations, formed by the accumulation of material in gutters or fissures. This is confirmed, for example, by the study of Szuszkiewicz et al. (2016), who showed that soil composition is more influenced by the bedrock than by the type of pedogenesis. This is confirmed by CA in the case of edifisols collected in the Lublin area, which divides these soils according to the type of 'bedrock'.

Analysis of the I_{geo} magnitude for the soil profiles analysed showed the lowest values in profiles 1LU, 2LU, and 3LU by far, which are characterised by no or moderate pollution for most elements (Fig. 5). Only Cr exceeded values > 2, which indicates the highly contaminated category. I_{geo} values in profiles 4LU, 5LU, 6LU, 7LU and 8LU were characterised by contamination at moderate to extremely contaminated levels. Particularly high values were recorded for Ni, Cu, Zn and Cr. Zn in profiles 5LU and 6LU and lead in profile 8LU reached the pollution categories as extremely polluted. The largest oscillations occurred for Ni and Pb, where no enrichment was found in the profiles 1LU, 2LU and

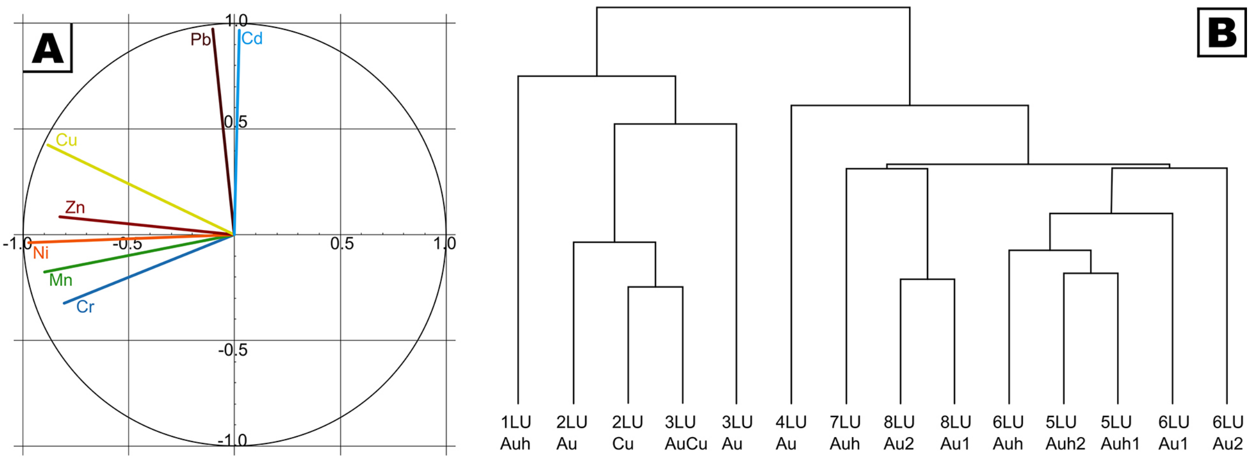

Fig. 4. A) Results of PCA; B) results of cluster analysis.

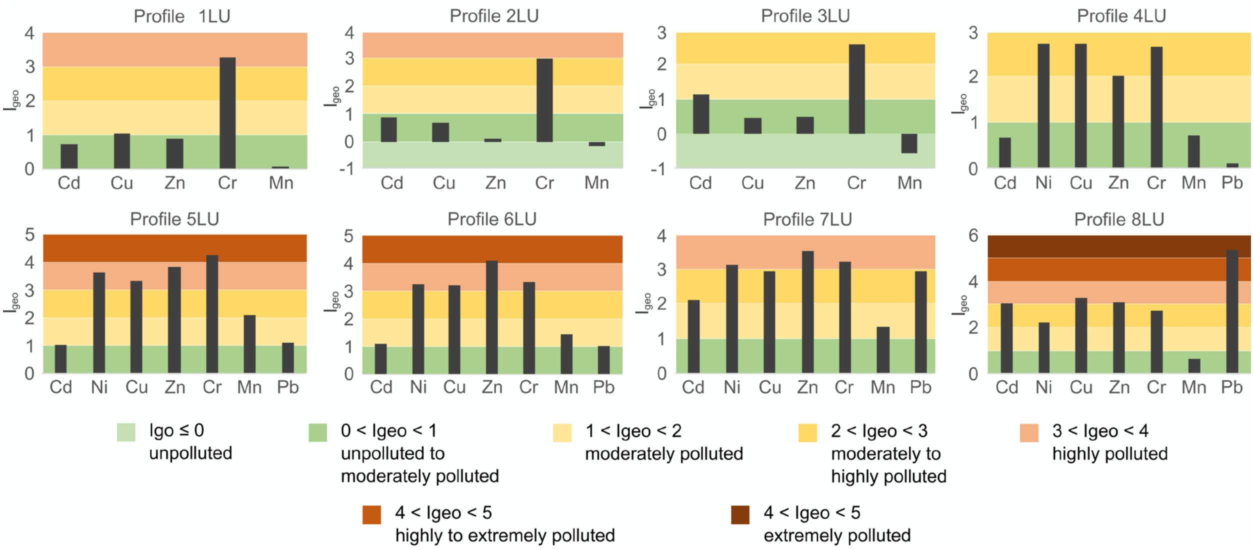

Fig. 5. Heavy metal content as determined by the indicator I_{geo}.

3LU, while strong contamination was found in the other profiles.

Overall, the studied soils were most contaminated with Cr, Zn, Cu and Ni, and the number of profiles classified as grade 3 (moderately and strongly contaminated) or higher was eight profiles for Cr and five profiles each for Zn, Cu and Ni. The average I_{geo} values for the studied HMs in the edifisols were in the following order: Mn < Pb < Cd < Ni < Cu < Zn < Cr (Table 5).

The average EF values for the analysed HMs were characterised by a wide variation (Fig. 6). In most of the profiles studied, the EF index for Mn and Pb was in the range 0 < EF > 2, indicating no enrichment of these elements. Only in profile 8LU, a very high enrichment of Pb was observed (37.60), which may be due to the immediate vicinity of the profile next to a frequently used road. Natural contents of the analysed elements were also recorded for Cd in profiles 4LU, 5LU, 6LU

Table 5. Geoaccumulation index, enrichment factor and potential environmental risk index.

0.00	Cd	Ni	Cu	Zn	Cr	Mn	Pb
Geoaccumulation Index (Igeo)							
Mean	1.34	1.81	2.21	2.26	3.13	0.70	1.32
Max	3.01	3.66	3.33	4.12	4.28	2.10	5.32
Min	0.67	0.00	0.46	0.12	2.57	−0.56	0.00
SD	0.81	1.56	1.25	1.60	0.56	0.90	1.91
Enrichment Factor (EF)							
Mean	3.72	3.13	5.12	6.10	10.57	1.71	5.71
Max	8.50	6.41	9.04	8.74	20.02	2.24	37.60
Min	0.76	0.00	3.67	2.66	4.76	1.41	0.00
SD	2.90	2.68	1.83	2.05	6.49	0.29	12.98
Potential Environmental Risk Index							
Profile	Cd	Ni	Cu	Zn	Cr	Mn	Pb
1LU	87.60	0.00	17.90	5.50	28.70	n.d.	0.00
2LU	90.60	0.00	12.30	1.80	24.10	n.d.	0.00
3LU	106.80	0.00	12.50	3.60	18.00	n.d.	0.00
4LU	71.60	48.50	49.00	6.00	18.40	n.d.	8.10
5LU	93.10	95.00	75.30	22.10	58.70	n.d.	16.20
6LU	100.60	71.80	70.60	29.50	30.30	n.d.	24.40
7LU	195.40	65.50	57.90	17.30	28.10	n.d.	58.40
8LU	363.70	60.60	74.20	12.70	19.70	n.d.	308.80

n.d. – not determined.

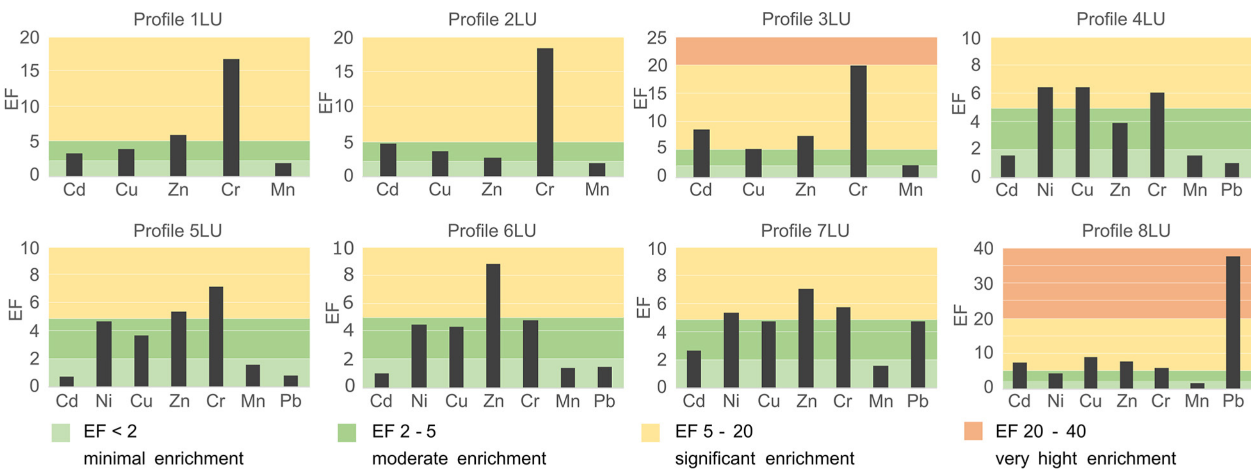

Fig. 6. Heavy metal content determined by the factor EF.

and for Ni in profiles 1LU, 2LU, 3LU. In the remaining profiles, the EF values calculated for Cd, Ni, Cu and Zn oscillated between 2.67 and 9.04, corresponding to enrichment categories ranging from moderate to significant enrichment. The highest EF values were recorded for Cr, which shows significant enrichment in almost all profiles. Particularly, high values for Cr were determined for profiles 1LU and 2LU, and profile 3LU was characterised by a very high enrichment of this element. Six profiles also showed EF values above 5, that is, significant enrichment for Zn. The average EF values for the studied HMs in the edifisols were in the following order: Mn < Cu < Zn < Ni < Cd < Cr < Pb (Table 5).

The determined integrated PLI contamination load made it possible to determine the amount of contamination, taking into account all the elements analysed. On its basis, it was found that all profiles were characterised by the presence of a contaminant (PLI ≥ 1).

The lowest PLI values (2.94–4.69) were recorded for profiles 1LU, 2LU, 3LU, 4LU, and thus in soils that formed from weathering mortar and brick and which are located in residential districts. In contrast, the highest PLI values (9.40–12.19) were found in profiles 5LU, 6LU, 7LU and 8LU located in industrial districts (Fig. 7). At the same time, large fluctuations of PLI were observed in the profiles. This may indicate a lack of uniformity in the distribution of elements and may also be due to the different origins of the strata building up the profiles (Arenas-Lago et al. 2014, Islam et al. 2015).

A low level (< 40) of potential ecological RI for Zn was found in all profiles (Table 5). For Cr, only one profile showed moderate risk, while moderate risk was found for five profiles for Cu and for four profiles for Ni. The index reached the highest values for Cd. In all profiles, it exceeded a value of 40, and in seven levels, the values fell into the category of significant or high and very high risk.

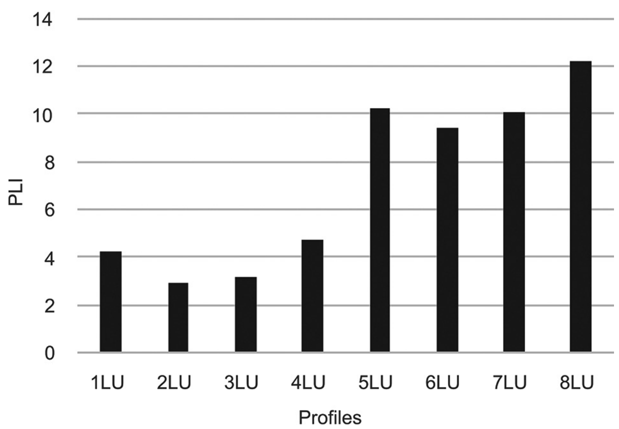

Fig. 7. PLI for the soil profiles studied.

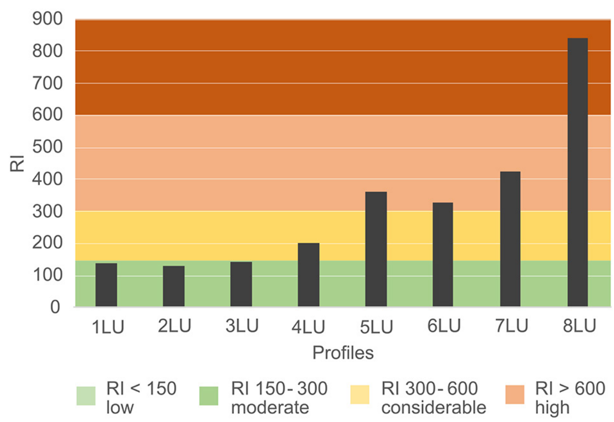

Fig. 8. Potential ecological risks for the soil profiles studied.

The highest level (364) was found for Cd and (309) for Pb in profile 8LU, located close to the road.

The graph of potential ecological RI (total index for all metals) is similar to the graph of PLI (Fig. 8). Profiles 1LU, 2LU and 3LU showed the lowest indicator category (129−141). Profiles 5LU, 6LU and 7LU showed significant ecological risk (360−422). The highest level of this indicator was 840 (very high potential ecological RI) for profile 8LU.

The determined geochemical indices indicated, in addition to the criteria contained in the Regulation of the Minister of the Environment of 1 September 2016 on the manner of conducting assessment of the pollution of the earth surface (Journal of Laws, item 1395), an elevated degree of pollution or enrichment with particular HMs.

Conclusions

This paper characterises edifisols − soils that form on man-made, artificial substrates. These substrates are various elements of abandoned or neglected buildings rain gutters, cracks and crevices in walls and flat sections of walls and ceilings. These soils are, therefore, relatively young, and their age depends on the age of the building on which these soils were created. The main factor influencing their physical and chemical properties is the type of building materials from which they formed. It mainly determines the granulometric composition, reaction, calcium carbonate content and the degree of saturation of the sorption complex with basic cations. Edifisols are soils with an alkaline pH (7.1–8.2), containing carbonates (up to 12.4%) and OC (up to 8.0%). The studied soils were characterised by a relatively high cation exchange capacity (up to 109.20 $\mathrm{cmol \cdot kg^{-1}}$), making them a suitable substrate for initial vegetation.

The geochemical indices used in this study (I_{geo}, PLI, EF) showed that the soils studied are characterised by an enrichment of HMs. Elements present in the studied soils in high concentrations include Cd, Ni, Cu and Cr, especially in the soils in the Zn troughs. The calculated potential ecological RI indicated that most of the profiles had moderate or higher ecological risk. The HMs content of the investigated soils is generally higher compared to the content in the soils of Lublin. Especially in the case of Cd, a highly toxic element, the contamination should be considered a serious health problem.

Although the study had its limitations (difficulty in determining GB), it can serve as an indicator of HMs contamination of urban areas of similar size and function. Based on calculation of selected geochemical indices such as EF, I_{geo}, PLI and RI, it was found that the investigated soils, characterised by elevated content of HMs of anthropogenic origin, can be considered as indicators of the environmental pollution. Statistical analyses (PCA and CA) have shown that HMs content is closely related to the type of substrate on which these soils were formed. HMs enrichment of the investigated soils may also be the result of many factors related to urban functioning, accompanied by the release of HMs into the environment. So, the development of research and monitoring of these soils are necessary. This is important for assessing the pollution status of the urban ecosystem and for analysing the relationships between environmental factors, anthropogenic pressure and human health.

Authors' contribution

TSz: conceptualization, investigation, methodology, resources, visualization, writing – original draft, writing – review & editing. AP: conceptualization, investigation, methodology, resources, writing – original draft, writing – review & editing. JCh: methodology, resources, writing – review & editing. MT: formal analysis, methodology, visualization, writing – original draft.

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