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Edifisols—a new soil unit of technogenic soils

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Abstract
Purpose A very specific type of urban soils forms on buildings. They are developed from or on technogenic substrates. This work was conducted to assess properties of Edifisols occurring in different regions of Europe and northwest Africa. Proposals are made for the terminology used and the systematic position of the investigated soils in the World Reference Base for Soil Resources.
Materials and methods The research was carried out in 2009–2012 in seven countries. Samples (23 in total) were accidentally collected from 15 municipalities of different size and function ranging from villages, small tourist resorts through medium-sized regional centres to metropolises. Soil material was collected from two types of building components: horizontal (roofs, tops of the buildings, bridge surfaces; 17 samples) and vertical (cracks and gaps in the walls; six samples). Soil materials were submitted to standard physical and chemical analyses to determine selected soil properties. For statistical analysis, STATISTICA 9.0 software was used.
Results and discussion The studied soils were very shallow, with the maximum thickness up to 10 cm. In the light of this study, several properties of the Edifisols should be regarded as characteristic, i.e. richness in artefacts and carbonates, very varied content of organic carbon (OC) and total nitrogen (N_t), elevated phosphorus content (P_{ca}) and heavy metal contamination. The results of the statistical analysis showed that climate was not a key factor in differentiation of the studied soils. The properties of Edifisols are linked to their position on the buildings. Edifisols in concave forms differ from those located on vertical and horizontal surfaces. Stages of the development of Edifisols are presented taking into account the functioning of the building in the course of time.
Conclusions Edifisols are formed as a result of initial, relatively natural soil-forming processes occurring on man-made substrates. Therefore, they may be considered as technogenic analogues of natural initial or weakly developed soils (Rendzic Leptosols, Folic Histosols and ornithogenic soils). They are often ephemeral soils susceptible to the influx of various contaminants. Due to specific location, genesis and properties, the qualifier Edific is proposed to supplement the next edition of World Reference Base (WRB).

Keywords Heavy metals · Soil classification · Technogenic soils · Technosols · Urban ecosystems

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1 Introduction

Human activity increasingly affects the natural environment. In 1900, only 13 % of the world's population lived in the cities (Saier 2007), but by 2011, the percentage had increased to 52 % (United Nations 2013). Huge changes in the soil cover and soil processes can be observed in different cities around the world (Effland and Pouyat 1997; El Khalil et al. 2013). The urban ecosystem is characterised by new types of human-made systems resulted from degradation, destruction and/or substitution of natural systems (Stroganova et al. 1998). Such ecosystem alterations are also identified as an 'urban stream syndrome'. This term describes the consistently observed ecological degradation of streams draining the urban land (Walsh et al. 2005).

The research on pedogenesis in the urban environment intensified in the 1990s. The urban soils can be defined as bodies located in urban ecosystems, which include a substrate formed by human activity (Blume 1989; Burghardt 1994). According to Sobocká (2003), this term can be also considered as a general terminological concept for soils occurring in urbanised, industrial, traffic, mining and military areas (SUITMA). The main factor for differentiation of SUITMAs from other soils is their location in the abovementioned areas. Therefore, the grouping of SUITMAs is found upon the management system which is an entirely different concept as opposed to soils used for agricultural purposes. The similar approach was used in the World Reference Base for Soil Resources to distinguish Technosols (IUSS Working Group WRB 2007; 2014). They are defined as soils whose properties and pedogenesis are dominated by their technical origin, having a significant amount of *artefacts*, or a *geomembrane*, or are sealed with *technic hard material* (IUSS Working Group WRB 2014).

A very specific type of urban soils develops on buildings. Already in 1840, Vasily Dokuchaev, the major precursor in the field of soil science, mentioned the soils formed on the walls of an abandoned 12-century fortress (Karpachevskiy 1983). On the other hand, Charles Darwin (1890) was the first scientist who described in details the soils formed on the buried ruins of the ancient Roman buildings. While examining the impact of worms on the formation of soil layers (moulds), the author stated that they play a key role in the partial decomposition of raw organic matter. Their activity accelerates the weathering process of structural elements of the buildings due to the increased amounts of humic acids. In addition, Darwin presented the cross sections of soils covering the Roman villas, basilicas and other buildings. The morphology of these soils in relation to their location was also analysed. Afterwards, such soils have not been studied in details until now. Knowledge about their properties is not well developed. However, there are some results of the botanical and archaeological studies conducted in areas where the development of vegetation and soils on the ruins of buildings led to the total concealment of the latter (Lisci et al. 2003; Ceschin and Caneva 2013). Despite the vast and pervasive human perturbation, urban ecosystems can provide a variety of substrata for colonization by flora and fauna (Forman and Godron 1986; McKinney 2002). The building construction materials can serve as ecological niches for various microbes (Hyvärinen et al. 2002), which support the growth of higher plants. Studies of Millard (2004) and Fornal-Pieniak and Chyliński (2012) showed that the establishment of plant communities on abandoned buildings is entirely spontaneous.

The initial study of the soils forming on buildings was conducted in Toruń, Poland by Charzyński et al. (2011a) and Charzyński and Hulisz (2013). The authors proposed a new term to describe these soils, i.e. Edifisols (Latin *aedificium* = building). This paper is a continuation and extension of the scope of these studies which aimed to characterize Edifisols occurring in different regions of Europe and northwest Africa. It was assumed that most properties of the soils will not vary much depending on the climatic conditions. However, taking into account that similar building materials are used all over the world, the main differentiating factor should be the location within various types of structural elements of a building. That is why, these still pilot studies, on the international scale, took into account the heterogeneity of Edifisols. They allowed the initial, more qualitative than quantitative assessment of the diversity of morphology and properties of these soils.

Moreover, for easier and better communication in the soil science community, proposals are made for the terminology used and the systematic position of the investigated soils in the in the next edition of World Reference Base for Soil Resources. This classification is subject to a constant process of evaluation and improvement, also in the group of Technosols (Séré et al. 2010; Charzyński et al. 2011b; Uzarowicz and Skiba 2011; Charzyński et al. 2013).

2 Study area

The research was carried out in seven countries and at 15 sites which are examples of areas with diverse, natural and anthropogenic environment (Table 1, Fig. 1). The municipalities of different size and function ranging from villages (Rimetea, Romania), small tourist resorts (Tossa de Mar, Spain and Chełmno, Poland) to medium-sized regional centres, such as Toruń (Poland) and Segovia (Spain), and finally metropolises (Milan, Porto, Barcelona, Marrakech and Dakar) were accidentally selected.

In Poland (Chełmno and Toruń), the climate is warm temperate, fully humid with warm summer (Cfb according to Köppen). More continental climatic conditions characterize the northwestern part of Romania (Rimetea; Dfb). Milan and Bergamo (Italy) have a relatively cool, mid-latitude variant of the humid subtropical climate (Cfa). Some Portuguese (Porto) and Spanish (Avila, Salamanca, Segovia) municipalities are located in the zone of moderate maritime climate with cooler

Table 1 General characteristics of the study sites

Site no.	Country	Coordinates	Location	Types of the building components	Plant species
Pl-Ch1	Poland	53° 21′ 0.27″ N 18° 25′ 22.64″ E	Chełmno, Old Market	Horizontal	*Acer platanoides*
Pl-Ch2		53° 21′ 0.65″ N 18° 25′ 11.66″ E	Chełmno, Dominikańska st.	Horizontal	*Humulus lupulus*
R-Ri1	Romania	46° 27′ 15.5″ N 23° 34′ 19.2″ E	Rimetea I	Horizontal	*Poaceae* sp., *Bryophyta*, *Capsella bursa pastoris*
R-Ri2		46° 27′ 16.3″ N 23° 34′ 10.6″ E	Rimetea II	Vertical	*Chelidonium majus*
I-Mi1	Italy	45° 28′ 13.23″ N 9° 10′ 37.34″ E	Milan I, Parco Semprione	Vertical	*Poaceae* sp.
I-Mi2		45° 28′ 22.75″ N 9° 11′ 48.26″ E	Milan II, Via Palestro	Vertical	*Parietaria* sp.
I-Be1		45° 42′ 07.68″ N 9° 40′ 38.7″ E	Bergamo I, Parco Suardi	Vertical	*Hedera helix*
I-Be2		45° 42′ 17.49″ N 9° 39′ 53.35″ E	Bergamo II, Mercato del Fieno	Vertical	*Parietaria* sp.
S-Sa1	Spain	40° 57′ 49.7″ N 5° 40′ 10.35″ W	Salamanca I, Pañuelas de San Blas	Horizontal	*Sedum album*
S-Sa2		40° 57′ 41.5″ N 5° 40′ 09.4″ W	Salamanca II, Plazuela de San Bartolome	Horizontal	*Sedum album*
S-Sa3		40° 58′ 10.4″ N 5° 39′ 21.2″ W	Salamanca III, Plaseo de la Estación	Horizontal	*Hedera helix*
S-Se1		40° 56′ 43.7″ N 4° 07′ 15.6″ W	Segovia, Calle de Santo Domingo de Silos	Horizontal	*Capsella* sp., *Poaceae* sp., *Parietaria* sp.
S-Av1		40° 39′ 27.09″ N 04° 42′ 17.75″ W	Avila I, Conde don Ramon	Horizontal	*Chelidonium majus*, *Poaceae* sp.
S-Av2		40° 39′ 26.05″ N 40° 39′ 26.05″ W	Avila II, Calle de Ramon y Cajal	Horizontal	*Poaceae* sp.
S-Gi1		41° 58′ 13.5″ N 2° 48′ 53.4″ W	Girona, Carrer de Carles Rahola	Horizontal	*Picris* sp., *Lactuca* sp.,
S-LM1		41 °42′ 30.3″ N 2° 50′ 46.5″ E	Lloret de Mar, Parc de Sant Cristófol	Horizontal	*Digitaria* sp.
S-TM1		41 °43′ 20.8″ N 2° 55′ 47.1″ E	Tossa de Mar, Correr del Torrent Viver	Horizontal	*Fumaria* sp.
S-Ba1		41° 25′ 13.2″ N 2° 5′ 47.4″ E	Barcelona I, Estación B. de Vallidrera	Horizontal	*Rubus* sp., *Poaceae* sp., *Pimpinella saxifraga*, *Elymus repens*
S-Ba2		41° 25′ 05.45″ N 2° 05′ 49.6″ E	Barcelona II, Camí del Fredolic	Horizontal	*Parietaria* sp.
P-Po1	Portugal	41° 08′ 34.5″ N 8° 36′ 59.0″ W	Porto, Rua da Vitória	Horizontal	*Amaranthus retroflexus* *Ipomoea* sp.
P-Li1		38° 42′ 22.0″ N 9° 10′ 27.4″ W	Lisbon, Rua Joáo de Oliveira Minguens	Horizontal	*Sedum album*, *Lactuca* sp., *Xeranthemum* sp.
M-Ma1	Morocco	31° 36′ 50.70″ N 8° 01′ 00.9″ W	Marrakech, Menara Gardens	Horizontal	*Capparis* sp.
Se-Da1	Senegal	14° 40′ 05.92″ N 17° 23′ 51.37″ W	Dakar, Ile de Gorée, Rue de Foncin	Vertical	*Parietaria* sp.

and dry summers (CsB), while subtropical Mediterranean climate with mild winters and warm summers (Csa) is typical for such Spanish cities and towns like Barcelona, Tossa de Mar, Girona and Lloret de Mar. The climate in African locations (Marrakech, Morocco and Dakar, Senegal) is generally warm, semi-arid with a short rainy season and a lengthy dry season (BSh)—Martyn (1992), Kottek et al. (2006).

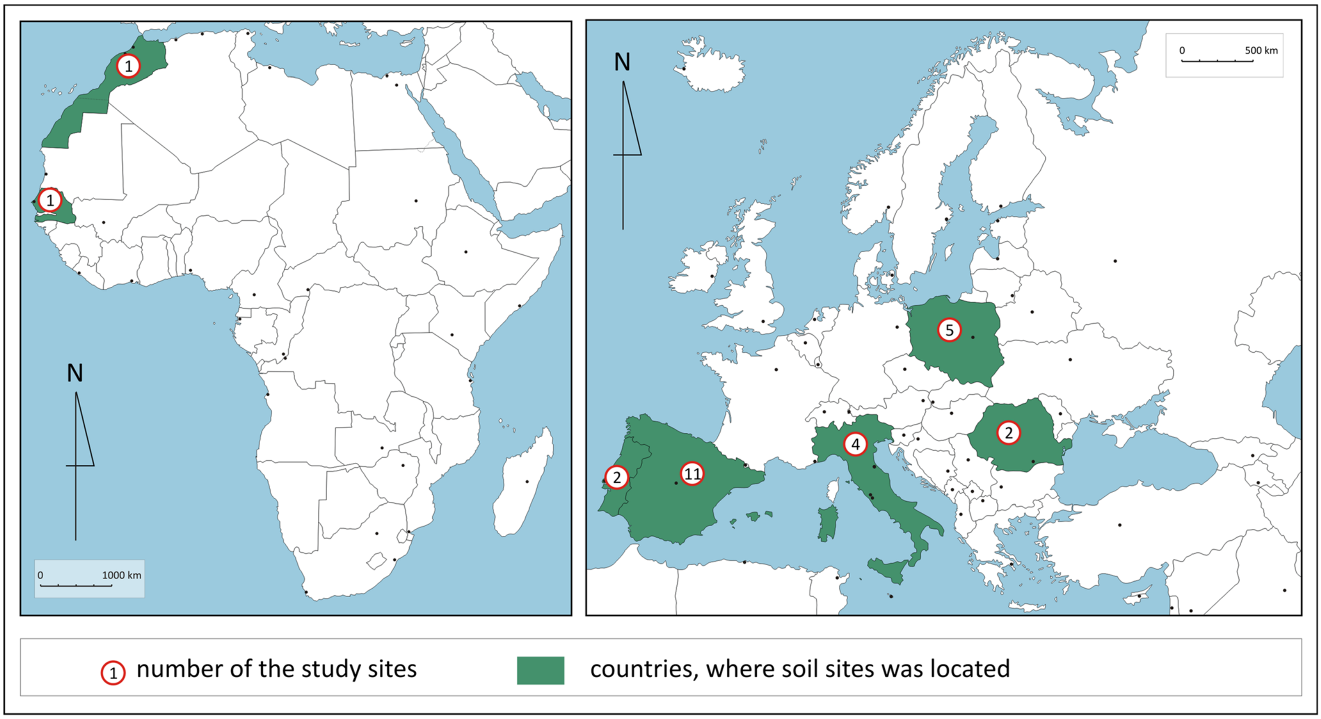


Fig. 1 Location of the study sites

3 Materials and methods

3.1 Fieldwork and laboratory analysis

The research was conducted in 2009–2012. In the selected locations, the reconnaissance fieldwork was carried out in search of poorly maintained or abandoned buildings. The main criterion for the selection of the study sites was the presence of vegetation as an indicator of soil-forming processes occurring on the buildings. The soil material (23 samples in total) was collected from two types of building components: horizontal (roofs, tops of the buildings, bridge surfaces; 17 samples) and vertical (cracks and gaps in the walls; six samples)—Table 1. Additionally, data from the previous publications of the authors (Charzyński et al. 2011a; Charzyński and Hulisz 2013) were used (5 samples) for comparative purposes, which represent the third type of the building components, i.e. concave forms (rain gutters). Also, the dominant vegetation was described at the sampling sites. The nomenclature of plants follows Flora Europaea (Tutin et al. 1993).

All samples were air-dried, disaggregated, homogenized and sieved through a 2-mm mesh. Due to the nature of the studied soils, i.e. developing on the technogenic rock, the whole fraction >2 mm was described as artefacts (IUSS Working Group WRB 2014). The soil material was submitted to standard physical and chemical analyses (van Reeuwijk 2002; Bednarek et al. 2004): particle size distribution (by the hydrometer method combined with the sieve method); pH in water and in 1 M KCl (soil to water ratio 1:2.5); $CaCO_3$ by the Scheibler method; organic carbon (OC) by sample oxidation in the mixture of $K_2Cr_2O_7$ and H_2SO_4 (Tyurin method); total nitrogen (N_t) by the Kjeldahl method; and phosphorus soluble in 1 % citric acid (P_{ca}). The content of lead, zinc and copper was determined using the atomic absorption spectrophotometry (AAS) after extraction of samples with a mixture of acids HF+ $HClO_4$.

3.2 Data analysis

Data for the 28 soil samples (including five soils described in the literature) were selected for statistical analysis. Scatter plots were drawn using STATISTICA 9.0 software (Statsoft Inc.) to determine the relationships between some soil parameters. The influence of climatic conditions (i.e. BSh, Cfa, Cfb, Csa, CsB and Dfb climates) and location (i.e. on horizontal and vertical building components or in concave forms) on soil properties was tested by Kruskal-Wallis one-way analysis of variance by ranks with post-hoc mean rank multiple comparison (Dunn test) (Zar 1999). The mean values of each soil parameter and standard deviations were calculated. STATISTICA 9.0 software (Statsoft Inc.) was used.

4 Results

4.1 Vegetation

The vegetation cover on the studied soils varied widely. Three groups of plants were distinguished: ruderal, forest and xerophilous (Table 1). The ruderal species were dominant as typical of the habitats disturbed by humans at all of the study sites (e.g. *Pimpinella saxifraga*, *Elymus repens*, *Lactuca* sp., *Rubus* sp. and *Poa* sp.). The second group consisted of forest plants that prefer shaded places and soils rich in nitrogen (*Hedera helix*, *Chelidonium majus*, *Acer platanoides*, *Digitaria* sp.; sites S-Sa3, S-Av1, Pl-Ch1, S-LM1). The last one was the xerophilous species (i.e. *Sedum album*, *Parietaria* sp. and *Xeranthemum* sp.; sites S-Sa1, S-Sa2, S-Se1, S-Ba2, P-Li1, I-Mi2, I-Be2), whereas the Edifisols in the rain gutters (sites from Pl-T1 to Pl-T5) were overgrown with both ruderal and forest plants, e.g. *Galinsoga parviflora*, *Epilobium adnatum*, *Acer negundo* and *Populus alba* (Charzyński et al. 2011a; Charzyński and Hulisz 2013).

4.2 Soil characteristics

The studied soils were very shallow (maximum thickness up to 10 cm), without visible horizonation and stagnic features (Fig. 2). Most of them (with the exception of soils occurring in the rain gutters) were developed from mineral materials, from sand to sandy loam (Fig. 3). The specific feature of those soils was a high content of artefacts (over 10 % in 15 samples) consisting mainly of brick fragments and slightly weathered mortar.

The content of organic carbon (OC) and total nitrogen (N_t) significantly varied in the studied soils (Tables 2 and 3). The lowest content of OC (4.1 g kg^{-1}) was recorded at site Se-Da1 located in the crack of the wall. The highest content (up to 394 g kg^{-1}—Pl-T3) was found in the soils developed from the organic material in the rain gutters. The total content of nitrogen (N_t) ranged from 0.4 (Se-Da1) to 21.1 g kg^{-1} (S-TM1). The C:N ratio was between 3 and 60. Generally, the soil parameters showed the commonly known linear relationship ($r=0.684$, $p=0.00006$—Fig. 4), but in some cases, the N_t content was disproportionately high in relation to the OC content. As a result, the C:N ratio was extremely narrow (3–5; S-Sa2, S-Sa-3, S-TM1, P-Li1 and I-Mi-1).

The pH values in the studied soils ranged from 6.1 to 8.5 in H_2O and from 5.7 to 7.9 in KCl, and $CaCO_3$ content was between 0.0 and 476 g kg^{-1} (Tables 2 and 3). The weakly acid reaction was mainly measured in the organic soils (rain gutters), poor in carbonates. Neutral and alkaline reaction of the samples was caused by the presence of carbonate-rich binder—a parent substance of masonry mortar.

The content of phosphorus soluble in 1 % citric acid (P_{ca}) ranged from 73 mg kg^{-1} (S-Av2) to 2650 mg kg^{-1} (I-Mi2)—Tables 2 and 3. The P_{ca} values were not associated with the OC and N_t content (Fig. 4).

The results of heavy metal analysis are presented in Fig. 5. The studied soils were characterised by a very wide range of lead (16–5944 mg kg^{-1}), zinc (30–687 mg kg^{-1}) and copper (7–654 mg kg^{-1}) content, which was considerably different from the background values for world soils. For comparison, the mean concentration of those elements in different soil units (surface horizons) can be as follows: 3–189 mg kg^{-1} for Pb, 17–125 mg kg^{-1} for Zn and 13–24 mg kg^{-1} for Cu (Kabata-Pendias and Pendias 2001). Extremely high Pb concentration was recorded in sample I-Mi2 (5944 mg kg^{-1}), Zn in samples S-Sa3, S-Ba1, P-Li1, Pl-T1, Pl-T2, Pl-T3 (>500 mg kg^{-1}) and Cu in samples Pl-T4, Pl-T5 (448 and 654 mg kg^{-1}, respectively). The analysed heavy metals demonstrated no statistically significant correlations (Fig. 4).

4.3 The impact of climate and location on soil properties

The results of Kruskal-Wallis one-way analysis of variance by ranks demonstrated that no significant difference between BSh, Cfa, Cfb, Csa, CsB and Dfb climates was found. However, the soils on different types of building components differed significantly. The Kruskal-Wallis test with post-hoc mean rank multiple comparison revealed that soils in concave forms were characterised by lower pH (pH-H_2O 6.7 and pH-KCl 6.4) in relation to soils on horizontal and vertical building components (Table 4). Moreover, soils in concave forms had significantly higher organic matter contents (207 g kg^{-1}) and C:N ratios (27). Furthermore, they significantly differed in $CaCO_3$ content which is lower (15 g kg^{-1}) than in soils on vertical locations (159 g kg^{-1}) (Table 4). Differences in other properties were not significant. Each of the analysed soil characteristics showed a great variability, as evidenced by SD, often above mean values (Table 4).

5 Discussion

5.1 Specificity of Edifisols and their similarity to other soils

In the light of this study, several properties of Edifisols should be regarded as characteristic, i.e. shallowness, richness in artefacts and carbonates, very varying content of organic carbon (OC) and total nitrogen (N_t), elevated phosphorus content (P_{ca}) and heavy metal contamination (Tables 2 and 3, Figs. 3 and 5). This

Fig. 2 Examples of Edifisols: *1* S-Av1, Avila I, Spain; *2* I-Be1, Bergamo I, Italy; *3* Pl-T4, Toruń, Poland; *4* S-Av2, Avila II, Spain; *5* R-Ri2, Rimetea, Romania; *6* Pl-T3, Toruń, Poland; *7* M-Ma1, Marrakech, Morocco; *8* I-Mi2, Milan II, Italy; *9* Pl-T5, Toruń, Poland; *10* P-Li1, Lisbon, Portugal; *11* I-Be2, Bergamo II, Italy; *12* Pl-T4, Toruń, Poland

description is in line with typical characteristics of urban soils given by Lehmann and Stahr (2007). The studied soils, excluding soils located in the rain gutters, are developed from technogenic substrates, usually abundant in carbonates. As a result, shallow soils, up to 10 cm thick, are formed with properties similar to weakly developed lithogenic soils (Rendzic Leptosols). On the other hand, the soils located in the rain gutters were characterised by low deposition of mortar and the presence of large amounts of organic matter derived from the decomposition of litter fall (leaves, flowers, small twigs) carried by the wind from trees growing nearby or washed off the roof. Their properties were similar to shallow mountain organic soils with folic horizon—Folic Histosols (Küfmann 2003).

Very specific features of certain soils (5 samples) include a very low C:N ratio (below 5), rarely found in natural or technogenic soils. This can probably be explained by a significantly increased input of nitrogen, mainly through bird droppings, which are also an important source of phosphorus (Crowther 1997). In this regard, the abovementioned Edifisols are similar to ornithogenic soils, common in the polar regions. According to Kim et al. (2012), the C:N ratio in the layers enriched with ornithogenic material may range from 1 to 4.

Soils in the cities are very often contaminated with heavy metals, which are a serious threat to the entire urban ecosystems (Grzebisz et al. 2002; Manta et al. 2002; Uzarowicz and Maciejewska 2012). That is why, some authors suggest to use certain trace elements (Cu, Pb, and Zn) as indicators of technosolisation (El Khalil

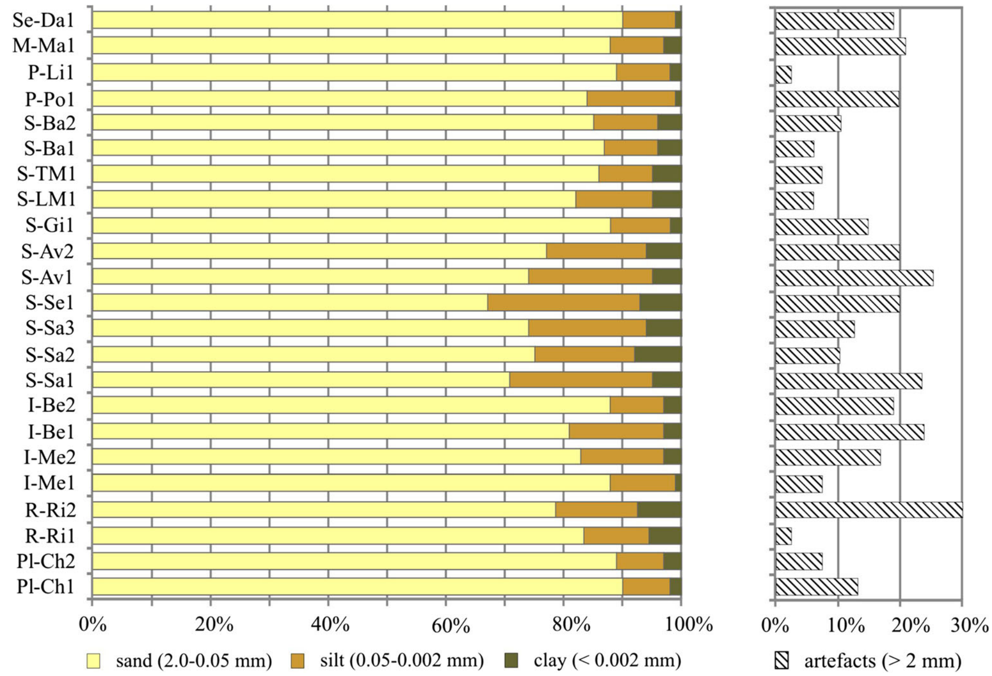


Fig. 3 Texture of the studied soils

et al. 2013). Most of the studied Edifisols were enriched with lead, zinc and copper. In relation to the background values given by Kabata-Pendias and Pendias (2001), 36 % of the analysed samples had

Table 2 Properties of the studied soils

Site no.	Depth [cm]	pH H_2O	pH KCl	OC [g kg^{-1}]	N_t	C:N	$CaCO_3$ [g kg^{-1}]	P_{ca} [mg kg^{-1}]
Pl-Ch1	0–3	8.1	7.8	18.9	1.10	17	70	284
Pl-Ch2	0–3	8.0	7.7	17.2	1.30	13	61	682
R-Ri1	0–5	8.0	7.6	28.5	1.90	15	299	393
R-Ri2	0–4	7.8	7.6	4.70	0.40	13	139	168
I-Mi1	0–5	7.6	7.4	21.8	7.90	3	50	831
I-Mi2	0–3	6.6	6.5	54.6	4.90	11	19	2650
I-Be1	0–3	7.6	7.5	59.8	5.40	11	81	666
I-Be2	0–3	7.8	7.6	27.4	7.60	4	188	387
S-Sa1	0–6	7.8	7.5	19.3	1.50	13	19	2610
S-Sa2	0–4	6.4	6.3	46.5	13.5	3	20	581
S-Sa3	0–6	7.2	7.0	29.5	6.30	5	2.0	434
S-Se1	0–4	7.6	7.4	12.1	1.10	11	44	683
S-Av1	0–5	8.5	7.9	13.3	1.10	12	34	107
S-Av2	0–6	8.3	7.6	10.8	0.80	14	9.0	73.0
S-Gi1	0–3	8.0	7.7	15.1	1.20	13	21	116
S-LM1	0–4	7.6	7.3	30.4	2.80	11	123	404
S-TM1	0–9	7.1	6.8	77.5	21.1	4	8.0	621
S-Ba1	0–3	7.4	7.2	57.4	4.00	14	78	119
S-Ba2	0–5	7.9	7.7	41.2	3.10	13	166	319
P-Po1	0–6	7.5	7.4	25.3	2.20	12	91	874
P-Li1	0–10	7.5	7.3	39.0	9.00	4	250	161
M-Ma1	0–5	7.4	7.4	57.8	4.90	12	166	442
Se-Da1	0–5	8.5	8.4	4.10	0.40	10	476	549

Table 3 Properties of the Edifisols forming in concave building components (rain gutters)—literature data

Site no.	pH		OC	N_t	C:N	$CaCO_3$	P_{ca}	Pb	Zn	Cu	Source
	H_2O	KCl	[g kg^{-1}]			[g kg^{-1}]		[mg kg^{-1}]			
Pl-T1	6.7	6.5	162	2.70	60	11	458	94	500	33	Charzyński et al. 2011a
Pl-T2	7.6	7.3	51.4	2.30	22	51	360	86	677	48	
Pl-T3	6.1	5.7	394	19.0	21	0.0	434	16	666	23	
Pl-T4	6.9	6.6	158	9.50	17	13	1050	214	30	654	Charzyński and Hulisz 2013
Pl-T5	6.4	6.0	270	17.2	16	2.0	1090	96	41	448	

elevated values for Pb content, 61 % for Zn and 68 % for Cu. These metals could enter Edifisols primarily through industrial and traffic pollution (e.g. S-Sa2, P-Li1, I-Mi2), building materials (e.g. S-Sa3, S-Ba1, Pl-T1-T5), etc. It should be noted that the dominant neutral and alkaline soil reaction resulting in immobilization of some metals and reduction of their bioavailability for plants is an additional factor responsible for their accumulation (Brümmer and Herms 1983).

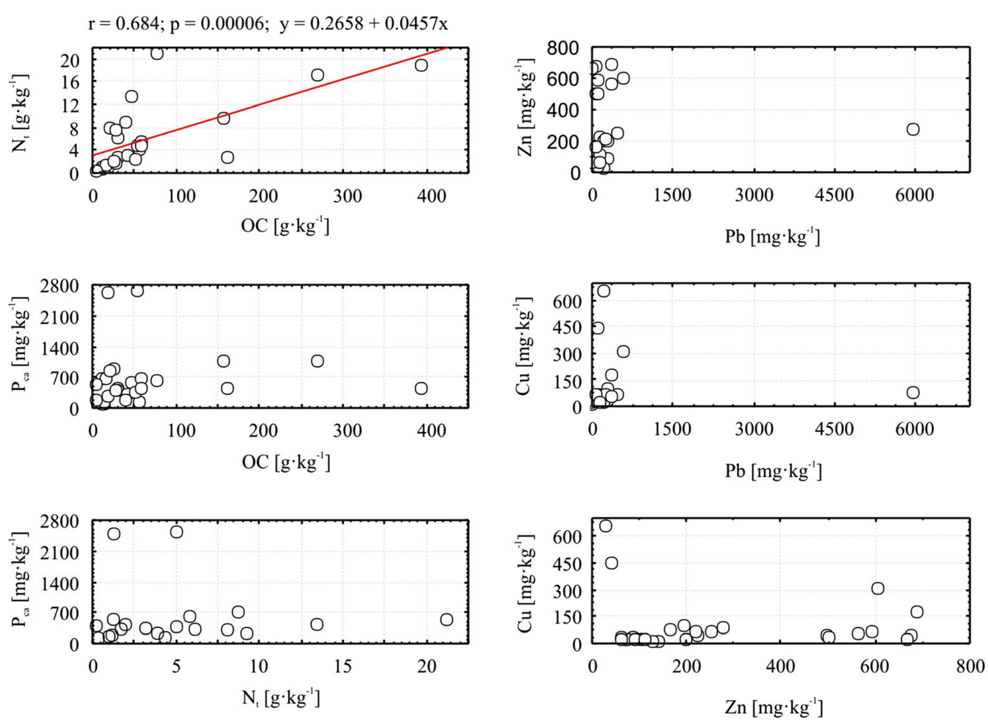
The comparison of soil properties between the three categories (i.e. soils formed on horizontal, vertical and in concave building components) by the Kruskal-Wallis test with post-hoc mean rank multiple comparison revealed distinct properties of soils formed in gutters. They were characterised by lower reaction, higher organic matter content and C:N ratio and lower calcium carbonate content. What is interesting is that soils formed on horizontal and vertical building components did not differ significantly. Moreover, the three investigated categories did not differ in pollution by heavy metals.

The statistical comparison showed that climate was not a key factor in the differentiation of the studied soil properties contrary to location. Due to the limited dataset, however, it should be assumed that the climate may affect the rate of soil formation processes in Edifisols. Therefore, the presented results should be interpreted with caution because of the pilot character of the study. This issue should be further researched.

5.2 Stages of the soil development on the buildings

Soils forming on buildings in the areas currently inhabited are usually ephemeral and young (Burghardt 2001). This can be associated with a specific character of objects on which they developed. Ruins of no historical value (e.g. S-Av1) might be demolished within a short time as they are a blot on city centres. The rain gutters with soils may break under the load

Fig. 4 Scatter plots of the selected soil parameters (n=28)



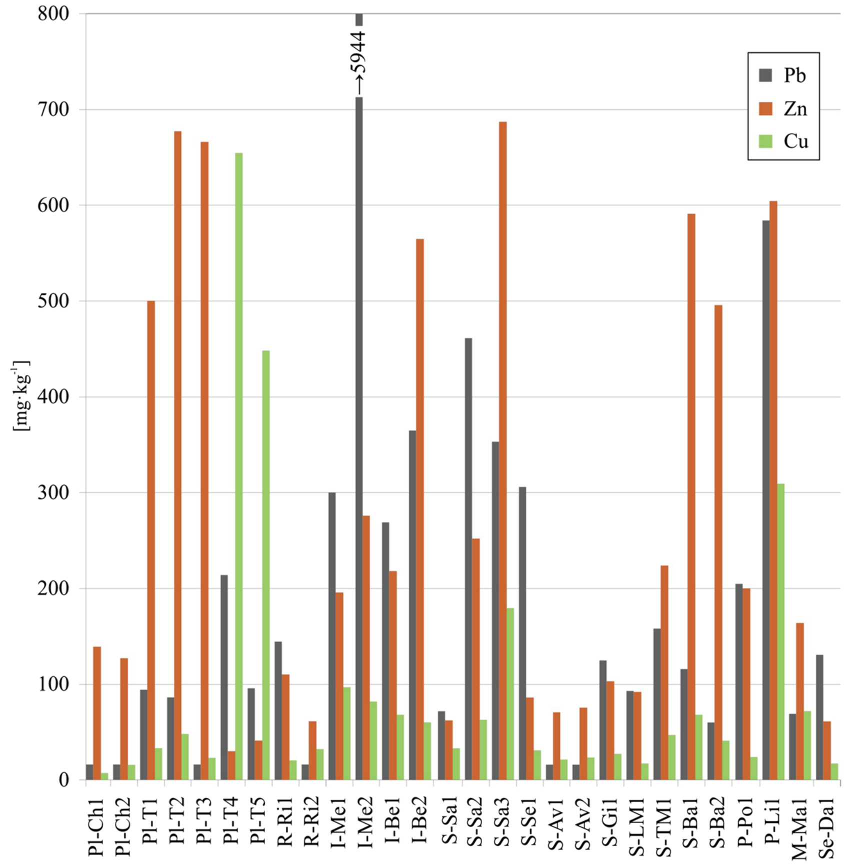


Fig. 5 Heavy metal content in the Edifisols

of deposited material or they may be cleaned (e.g. Pl-T2). Buildings of historical importance (e.g. I-Mi1), still used by man, are periodically cleaned of all the soil and vegetation. Buildings are a type of geomembrane which, in the case of Edifisols, blocks the contact with natural or technogenic soils occurring on the Earth's surface. Lack of soil sealing does not reduce the impact of the external environment on the soil development and properties.

Figure 6 presents the stages of the development of Edifisols taking into account the functioning of the building over time. After the construction of a building, the growth of plants and soil development on its surfaces depend on the building maintenance and the state of conservation (i.e. clearing and repairing), the building material and the climate. According to Lisci et al. (2003), it usually takes more than 10 years for plants to colonize a wall (in the Mediterranean Basin). Following the aforementioned authors, two modes of plant colonization on the buildings can be distinguished. The first one is independent of the position and moisture conditions. The initial deterioration of the building structure caused by

Table 4 Comparison of soil properties in different localities (mean±SD). Kruskal-Wallis test was applied with Dunn test as post-hoc nonparametric multiple comparisons. Treatments with no difference are marked by the same letter (a or b)

	Types of building components			Kruskal-Wallis test
	Horizontal	Vertical	Concave	
pH-H_2O	^{a}7.6±0.5	^{a}7.6±0.6	^{b}6.7±0.6	p=0.026
pH-KCl	^{a}7.4±0.4	^{a}7.5±0.6	^{b}6.4±0.6	p=0.014
OC [g kg^{-1}]	^{a}31.8±19.1	^{a}28.7±24.0	^{b}207±130	p=0.0067
N_t [g kg^{-1}]	4.50±5.50	4.40±3.30	10.4±7.80	ns
C:N	^{a}11±4	^{a}9±4	^{b}27±18	p=0.0013
$CaCO_3$ [g kg^{-1}]	^{ab}86±88	^{a}159±167	^{b}15±21	p=0.0269
P_{ca} [mg kg^{-1}]	524±587	875±899	678±360	ns
Pb [mg kg^{-1}]	165±167	1171±2342	101±71	ns
Zn [mg kg^{-1}]	240±212	230±186	383±325	ns
Cu [mg kg^{-1}]	59±76	59±30	241±292	ns

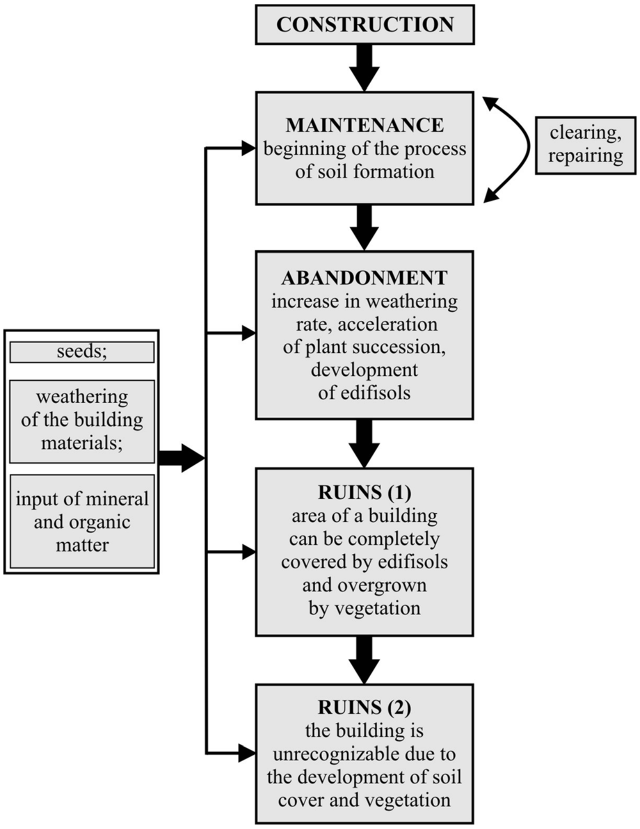


Fig. 6 Block diagram presenting the development of the Edifisols in relation to the building's age and fate

Fig. 7 The example of the extreme Edifisols—an unrecognizable building ruins completely covered by soil and vegetation (Tikal, Guatemala)

bacteria, fungi and lichens can lead to the formation of a substrate suitable for the germination of seeds of hardy pioneer plants. The biological processes favour the intensification of physical and chemical weathering of building elements. Simultaneously, it may be followed by the input of mineral and organic matter (atmospheric dust, bird excrements and human wastes). The detritus of the pioneer plants can also form a soil substrate (Folic layer). The second mode of colonisation occurs mostly on horizontal positions with a sufficient water supply. In such conditions, mosses are the pioneer plants. They accelerate the formation of an initial soil substrate by trapping the atmospheric dust.

In areas formerly inhabited and now abandoned, where a long-term soil-forming process occurs and is uninterrupted by human intervention, an increase in the thickness of Edifisols is observed. It can lead to a complete coverage of the buildings, first by plants and then by the soil cover. This process lasts until the transformation of a building into a natural-looking land form, e.g. the Mayan ruins in Mexico and Guatemala (Fig. 7). However, in the case of smaller buildings, e.g. Roman villas, the ruins can totally disappear, covered by well-developed soils (Darwin 1890; Barone et al. 2013; Fig. 7), which originally started as Edifisols. According to WRB (IUSS Working Group WRB 2014), they start as Technosols and when they become thicker, their Reference Soil Group may change.

5.3 Proposal for classification of Edifisols

So far, the studied soils have not been included in a proposal for classification of urban soils, except for a suggestion made by Burghardt (1994) who, however, outlined only one of the possible scenarios for the development of soils on man-made structures, i.e. the formation of so called 'aerosols' as a result of aeolian accumulation of the dust produced by vehicular traffic.

The newest developments in the taxonomy of technogenic soils i.e. a proposal to integrate the systematic of urban soils into the new Russian soil classification system (Prokof'eva et al. 2013) or the Greinert concept for Systematics of Polish Soils (Greinert et al. 2013) do not ensure an adequate classification of Edifisols due to the lack of an appropriate unit.

Based on the research on soils developing on buildings, we propose a new taxonomic unit called Edifisols (Latin *aedificium*=building), which should be introduced in the technogenic soils taxonomies. It is also important to provide a possibility of precise classification of the described soils in the international classification of WRB because they develop worldwide in urbanised areas. In the currently valid edition of WRB (IUSS Working Group WRB 2014), Edifisols may be classified as Isolatic Technosols or Leptosols, Histosols and Regosols with the Isolatic supplementary qualifier. It also seems likely (although further studies are required to confirm it) that some of the well-developed soils covering the ancient ruins (see e.g. Darwin 1890; Barone et al. 2013) could meet the criteria for Pheozems and Umbrisols. Isolatic qualifier comprises two opposite types of soils, i.e. constructed soils of 'green roofs', intentionally placed on the top of buildings and Edifisols. These two groups of soils are characterised by different genesis and properties. The above classification does not specify the nature of Edifisols, so the next edition of WRB should include the additional qualifier Edific. The definition of this qualifier should account for location on the buildings and spontaneous development as a result of weathering of technogenic material in situ with the supply of mineral and organic matter. The proposal is given below:

Edific (ef)

having a thickness of ≤100 cm and developing spontaneously on buildings, without intentional human activity from *technic hard* material as a result of weathering of technogenic substrates in situ and with the supply of mineral and organic matter carried by wind, rainwater or animals.

6 Conclusions

This paper characterises a new unit of technogenic soils, which is proposed to be called Edifisols. These soils can develop on different types of building components: horizontal (e.g. flat roofs, tops of buildings, bridge surfaces), vertical (cracks and gaps in walls) and concave (e.g. rain gutters).

Edifisols are formed as a result of initial, relatively natural soil-forming processes occurring on technogenic substrates. Therefore, they may be considered as certain analogues of natural initial or weakly developed soils (Rendzic Leptosols, Folic Histosols and ornithogenic soils). They are often ephemeral soils susceptible to an influx of any kind of contamination and transformation. The influence of the natural environment on the discussed soils is mainly manifested in the presence of different plant species (e.g. xerophilous, thermophilous).

The results of the statistical analysis showed that climate settings in Poland, Romania, Italy, Spain, Portugal, Morocco and Senegal did not affect the studied properties of soils. The properties of Edifisols are closely linked to their position on buildings. Within the investigated types of Edifisols, only soils formed in the concave structural elements have distinct characteristics. They are characterised by a higher content of organic matter, higher values of the C:N ratio, lower pH and lower content of $CaCO_3$ in comparison with Edifisols developed on horizontal and vertical elements.

According to the World Reference Base for Soil Resources (IUSS Working Group WRB 2014), Edifisols can be classified using the Isolatic qualifier which refers to soils formed both as a consequence of intentional human activity and with no human impact. According to the authors, the next edition of WRB should be supplemented with the qualifier Edific (ef) to be used for the Reference Soil Groups of Technosols, Histosols, Leptosols, Phaeozems, Umbrisols and Regosols.

The authors have undertaken a pioneer challenge to identify the nature of Edifisols. The research on those interesting and worldwide occurring technogenic soils should be continued. It seems that the most important aspect of future research should consist in the determination of the rate of soil formation on the buildings under various climatic conditions and the plant cover.

References

Barone PM, Mattei E, Pettinelli E (2013) Non-invasive archaeological exploration in stratigraphically complex rural settings: an example from Ferento (Viterbo, Italy). Archaeol Anthropol Sci 5:267–273

Bednarek R, Dziadowiec H, Pokojska U, Prusinkiewicz Z (2004) Eco-pedological studies. PWN, Warsaw (in Polish)

Blume HP (1989) Classification of soil in urban agglomerations. Catena 16:269–275

Brümmer G, Herms U (1983) Influence of soil reaction and organic matter on the solubility of heavy metals in soils. In: Ulrich B, Pankrath J (eds) Effects of accumulation of air pollutants in forest ecosystems. D. Reidel Publishing Company, Dordrecht, pp 233–243

Burghardt W (1994) Soils in urban and industrial environment. Z Pflanzenernähr Bodenkd 157:205–214

Burghardt W (2001) Soils of low age as specific feature of urban ecosystem. In: Sobocká J (eds) Soil Anthropization 6. Bratislava, pp 11–17

Ceschin S, Caneva G (2013) Plants as bioindicators for archaeological prospection: a case of study from Domitian's Stadium in the Palatine (Rome, Italy). Environ Monit Assess 185:5317–5326

Charzyński P, Hulisz P (2013) Soils forming on buildings in Toruń. In: Charzyński P, Hulisz P, Bednarek R (eds) Technogenic soils of Poland. Polish Society of Soil Science, Toruń, pp 81–93

Charzyński P, Bednarek R, Chmurzyński M (2011a) Properties of soils forming on the buildings in Toruń city. In: Jankowski M (ed) Selected problems of genesis, systematics, management and soil protection in region of Kuyavia and Pomerania. PTSH, PTG, Toruń:11–28 (in Polish)

Charzyński P, Bednarek R, Świtoniak M, Żółnowska B (2011b) Ekranic Technosols and Urbic Technosols of Toruń necropolis. Geologija 53(4):179–185

Charzyński P, Bednarek R, Greinert A, Hulisz P, Uzarowicz Ł (2013) Classification of technogenic soils according to WRB system in the light of Polish experiences. Soil Sci Ann 64(4):145–150

Crowther J (1997) Soil phosphate surveys: critical approaches to sampling. Anal Interpretation Archaeol Prospect 4:93–102

Darwin C (1890) The formation of vegetable mould through the action of worms with some observations on their habits. D. Appleton & Co, New York

Effland WR, Pouyat RV (1997) The genesis, classification, and mapping of soils in urban areas. Urban Ecosyst 1:217–228

El Khalil H, Schwartz C, El Hamiani O, Kubiniok J, Morel JM, Boularbah A (2013) Distribution of major elements and trace metals as indicators of technosolisation of urban and suburban soils. J Soils Sediments 13:519–530

Forman RTT, Godron M (1986) Landscape ecology. Wiley, New York

Fornal-Pieniak B, Chyliński K (2012) Diversity of spontaneous flora of unused industrial buildings in Warsaw, Poland. Ekológia (Bratislava) 31(4):379–389

Greinert A, Fruzinska R, Kostecki J (2013) Urban soils in Zielona Góra. In: Charzyński P, Hulisz P, Bednarek R (eds) Technogenic soils of Poland. Polish Society of Soil Science, Toruń, pp 31–54

Grzebisz W, Cieśla L, Komisarek J, Potarzycki J (2002) Geochemical assessment of heavy metals pollution of urban soils. Pol J Environ Stud 11(5):493–499

Hyvärinen A, Meklin T, Vespäläinen T (2002) Fungi and actinobacteria in moisture-damaged building materials: concentration and diversity. Int Biodeterior Biodegrad 49:21–25

IUSS Working Group WRB (2007) World references base for soil resources 2006, update 2007. World Soil Resources Reports, 103. FAO, Rome

IUSS Working Group WRB (2014) World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps World Soil Resources Reports, 106. FAO, Rome

Kabata-Pendias A, Pendias H (2001) Trace elements in soils and plants. CRC Press LLC, Boca Raton

Karpachevskiy LO (1983) The landscape mirror. Mysl, Moscow (in Russian)

Kim OS, Chae N, Lim HS, Cho A, Kim JH, Hong SG, Oh J (2012) Bacterial diversity in ornithogenic soils compared to mineral soils on King George Island, Antarctica. J Microbiol 50(6):1081–1085

Kottek M, Grieser J, Beck C, Rudolf B, Rubel F (2006) World map of the Köppen-Geiger climate classification updated. Meteorol Z 15:259–263

Küfmann C (2003) Soil types and eolian dust in high-mountainous karst of the Northern Calcareous Alps (Zugspitzplatt, Wetterstein Mountains, Germany). Catena 53:211–227

Lehmann A, Stahr K (2007) Nature and significance of anthropogenic urban soils. J Soils Sediments 7(4):247–260

Lisci M, Monte M, Pacini E (2003) Lichens and higher plants on stone: a review. Int Biodeterior Biodegrad 51:1–17

Manta DS, Angelone M, Bellanca A, Neri R, Sprovieri M (2002) Heavy metals in urban soils: a case study from the city of Palermo (Sicily), Italy. Sci Total Environ 300(1–3):229–243

Martyn D (1992) Climates of the world. Elsevier Science, Amsterdam

McKinney ML (2002) Urbanization, biodiversity and conservation. Bioscience 52:883–890

Millard A (2004) Indigenous and spontaneous vegetation: their relationship to urban development in the city of Leeds, UK. Urban For Urban Green 3:39–47

Prokof'eva T, Gerasimova M, Lebedeva I, Martynenko I (2013) An attempt of integrating the systematic of urban soils into the new Russian soil classification system. Soil Sci Ann 64(1):24–29

Saier MH (2007) Are megacities sustainable? Water Air Soil Pollut 178:1–3

Séré G, Schwartz C, Ouvrard S, Renat JC, Watteau F, Villemin G, Morel JL (2010) Early pedogenic evolution of constructed Technosols. J Soils Sediments 10:1246–1254

Sobocká J (2003) Urban soils vs. anthropogenic soils, their differentiation and classification. Final Program and Abstracts Book, SUITMA Int. Conf., July, 9–11 2003, Nancy, France, pp 41–42

Stroganova M, Miagkova A, Prokofieva T, Skvortsova I (1998) Soils of Moscow and urban environment. Moscow

Tutin TG, Burges NA, Chater AO, Edmondson JR, Heywood VH, Moore DM, Valentine DH, Walters SM, Webb DA (eds) (1993) Flora Europaea, vol 1, 2nd edn. Cambridge University Press, Cambridge, reprint 1996

United Nations (2013) World urbanization prospects: the 2011 revision population database. New York, USA (http://esa.un.org/unup/CD-ROM/Urban-rural-Population.htm)

Uzarowicz Ł, Maciejewska A (2012) Assessment of properties of technogenic soils Technosols containing iron sulfides. Soil Sci Ann 63(3):37–42 (in Polish with English abstract)

Uzarowicz Ł, Skiba S (2011) Technogenic soils developed on mine spoils containing iron sulphides: mineral transformations as an indicator of pedogenesis. Geoderma 163:95–108

van Reeuwijk LP (ed) (2002) Procedures for soil analysis. ISRIC, Wageningen

Walsh CJ, Roy AH, Feminella JW, Cottingham PD, Groffman PM, Morgan RP (2005) The urban stream syndrome: current knowledge and the search for a cure. J N Am Benthol Soc 24:706–723

Zar JH (1999) Biostatistical analysis. Prentice-Hall, Englewood Cliffs