Evaluation of Human-impacted Soils in Szeged (SE Hungary) with Special Emphasis on Physical, Chemical and Biological Properties

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Abstract

The main differences between urban and natural soils result from the accumulation of anthropogenic materials, which form a cultural layer with specific properties and composition. Szeged is an ideal sampling area for researching urban soils due to intensive artificial infill following the 1879 Great Flood as well as other anthropogenic activities owing to the expansion of urban functions that define the morphology of soils here. We took samples at 25 sites in 2005 and 2006 from horizons of soil profiles located in city areas and peripheral profiles of the original genetic soil type for physical and chemical analysis. Average topsoil samples (0-10 cm depth, 2-4 m^2) were taken near the profiles in order to determine the concentrations of heavy metals (Co, Cu, Ni, Pb, Zn, Cr, Cd) in these soils so as to classify them according to the toxic properties described in the World Reference Base for Soil Resources and to identify the origins of these elements (anthropogenic vs. geogenic). Topsoil samples were also collected in October 2006 at 10 sites representing three zones (city, suburban, peripheral zone) to survey some basic biological properties of mesofaunal elements and their community structure.

We claim that all the soil parameters except total salt content are excellent markers of human influence. This is well supported by a discriminant analysis of the above-mentioned parameters. In our analysis of heavy metals, we distinguished elements of anthropogenic (Cu, Ni, Pb, Zn) and natural or lithogenic (Co, Cr, Cd) origin. Following a quantitative evaluation of elements, according to the proposal of the World Reference Base for Soil Resources, profiles where the concentration of any metal element exceeded the limit values in the topsoil were marked with the suffix Toxic. According to a mezofauna (oribatid mites, collembolans) investigation, it seems that the intermediate suburban zone has a more heterogeneous and stable mezofaunal community structure than the other two zones. The lowest abundance values were found in the city zone. Based on our evaluation of diagnostic properties and the results of our discriminant analysis, four main soil types can be identified in Szeged related to the degree of human influence.

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Introduction

In the past, classification systems and research into the physical and chemical properties of soils focused on the requirements of farming and forestry; urban soils were almost totally neglected (Thornton, 1991). The investigation of urban soils has only become a focus of scientific research during the past few years (Birch and Scollen, 2003; Murray et al., 2004). Due to increasing urbanization and industrialization, human activity results in soil contamination, degradation, destruction, and soil formation from anthropogenic parent materials (Beyer, 2001). Thus the genesis of these modified soils is based on conditions that do not occur in natural or agricultural systems. The same goes for the chemical composition of urban soils, since atmospheric deposition, waste disposal, and construction activities lead to specific urban patterns (Herget, 1996; Meuser, 1996; Radtke et al., 1997; Hiller and Meuser, 1998). Consequently research on urban soils can generally be divided into two approaches that complement one another. One approach is research on the genesis of urban soils and its meaning as part of an ecosystem, while the other focuses on contamination and harmful disturbances of urban soils with negative consequences on the quality of life (Norra and Stüben, 2003).

During urbanization and its renewal, the landscape is reshaped, filled, or cut. This modification of the topography creates man-made land in cities (Spirn, 1984). According to Billwitz and Breuste (1980), a typical feature of urban ecosystems is anthropogenic deposition of different materials several meters thick. This cultural layer buries the natural soil and is characterized by high alkalinity, stratification, evident traces of different technogenic impacts, soil surface sealing, compaction, mixing of anthropogenic materials with natural parent materials, and increased contents of nutrients and toxic elements (Alexandrovskaya and Alexandrovskiy, 2000). This thick culture layer is especially relevant in Szeged (SE Hungary), where the original surface of the city was elevated by several meters by intensive anthropogenic activities (infilling) following the Great Flood of 1879 (Andó, 1979).

Craul and Klein (1980) observed vertical and spatial variability of urban soils: urban soil profiles show abrupt changes from one layer to another depending on the construction history of the soil. This abrupt change is commonly referred to as a lithologic discontinuity with a created interface. Restriction in drainage and aeration of urban soils can be caused by these abrupt textural and structural changes within the profile. Spatial variability may be just as complex as vertical variability. Therefore it is not uncommon to find a dramatic contrast in urban profiles from one tree planting pit to another on the same street within the same block (Craul and Klein, 1980).

Nevertheless, urban soils are recipients and indicators of various pollutants that accumulate over a long time. The health of inhabitants largely depends on the conditions of urban soils (Simpson, 1996). There are various pollution sources in urban areas: vehicle exhaust (Harrison et al., 1981; Ho and Tai, 1988), waste incineration (Schuhmacher et al., 1997), the metalliferous industries of mining, smelting, and manufacturing (Thornton, 1991), airborne dust (Simonson, 1995), road abrasion, and building materials. However, traffic is the major pollution source in those urban areas where there are no significant industrial and mining activities (Zhang, 2005). This is true for Szeged, where the light and food industries are dominant, and are not responsible for the emission of heavy metals.

Modified physical and chemical parameters exert influences on soil organisms. As a result, the biological properties of urban soils also differ from those of managed and natural systems (White and McDonnell, 1988). One general goal of soil research is to evaluate the effect of human activity by applying biological indicators, as physical and chemical parameters cannot completely describe the quality of urban soil. The study of microarthropod communities can be a powerful method for assessing soil quality, as the life cycles of these edaphic animals strictly depend on soil characteristics. In terrestrial ecosystems, oribatid mites and collembolans are represented by a number of species (Stanton, 1979). They generally account for up to 95% of all microarthropods in grasslands and play an important role in decomposing organic materials, changing the physical and chemical texture of soils, cycling nutrients, and conserving the soil environment (Wallwork, 1983). The close relationship between edaphic invertebrates and their ecological niches in the soil, and the fact that many of them live a sedentary life, provide a good basis for the bioindication of changes in soil properties and the extent of human impact (van Straalen, 1998). Collembolans and oribatid mites are excellent means for assessing and monitoring soil quality and predicting the activity of soil processes, especially those that occur due to human intervention.

The major goals of the present study can be summarized as follows:

- to examine the physical and chemical properties of anthropogenic soils that differ from natural soils (e.g. artefacts[1], organic matter content, quality of organic matter)
- to determine heavy metal concentrations in order to differentiate anthropogenic from lithogenic origins and to mark those profiles where the concentration of any metal element exceeds the limit values in the topsoil with the suffix Toxic (IUSS Working Group WRB, 2007).
- to survey the mezofaunal communities (oribatid mites, collembolans) of soils in city, suburban and peripheral zones in order to get information on the quality and quantity of these communities in urban and natural soils;
- to classify individual soil horizons into natural and anthropogenic groups using discriminant analysis.

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[1] The term artefact is used here according to the WRB-definition (FAO et al., 2006). Therefore, artefacts (from Latin *ars*, art, and *facere*, to make) are solid or liquid substances that are: 1) one or both of the following: a, created or substantially modified by humans as part of an industrial or artisan manufacturing process; or b, brought to the surface by human activity from a depth where they were not influenced by surface processes, with properties substantially different from the environment where they are placed; and 2) have substantially the same properties as when first manufactured, modified or excavated.

Area descriptions, materials studied, and methods

Szeged is a major city in Hungary with an elevation of 84 m a.s.l. The surface of the area is largely affected by the fluvial systems of the rivers Tisza and Maros, which are composed of active and inactive channels (Marosi and Somogyi, 1990). After the Great Flood of 1879, two major flood protection systems were devised: one relying on the newly constructed ring of dams embracing the inner core areas and the other based on the elevation of the original surface via significant infilling of low-lying areas. The greatest thickness of infill, exceeding 6 m, is recorded in the downtown area near the downtown bridge (Andó, 1979).

Over 120 soil samples were taken from the horizons of 25 profiles in the city and its peripherals (as control samples) during 2005 and 2006 for physical and chemical analysis. The locations of urban profiles influenced by human activities were determined by considering the degree and type of anthropogenic activities: the profiles were sampled at sites affected by different extents of artificial infill. Selection was made according to maps depicting the thickness of infill in the city area (1. profiles completely composed of infill; 2. so-called mixed profiles consisting of a considerable amount of infill material and buried soil horizons; and 3. natural profiles located in the outskirts of the city). Furthermore, the profiles represented sites with different land uses (e.g. park, built-in area, unpaved road, plot, orchard, abandoned area) (see Table 1, Fig. 1).

Average samples were also taken from the topsoil of the profiles (depth of 0-10 cm covering an area of 2-4 m^2) to determine the total heavy metal content.

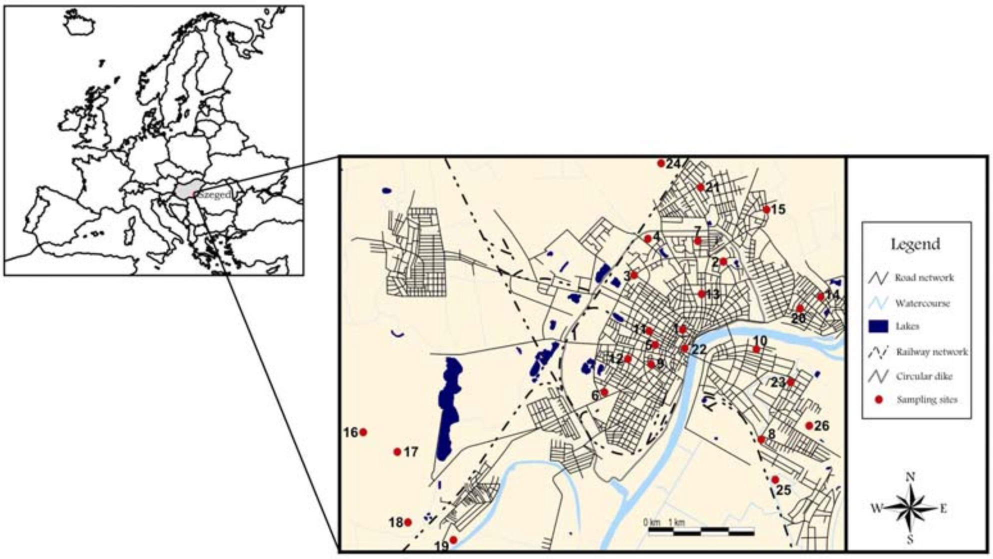

Fig. 1: Location of sampling sites in Szeged.

Table 1: Characterization of the sample sites

Profiles	No. of soil horizons	Bedrock	Morphology	Perched groundwater depth (cm)	Landscape utilization (2005)	Vegetation cover (2005)
1.	6	infill	plain	> 200	built-in area	-
2.	4	loess	plain	> 75	meadow	Lolium perenne, Taraxacum officinale
3.	9	loess	plain	> 125	bicycle road	Taraxacum officinale, Elymus repens, Lolium perenne,
4.	6	infill	depression	> 80	abandoned area	Rosa canina, Phragmites australis, Poa trivialis, Arrhenatherum elatius
5.	5	infill	plain	> 140	sidewalk	-
6.	6	infill	plain	> 150	built-in area	Elymus repens, Ambrosia artemisiifolia, Erigeron canadensis, Chenopodium album,
7.	4	loess	plain	> 180	built-in area	-
8.	8	infill	slope	> 180	meadow	Taraxacum officinale, Elymus repens
9.	4	infill	plain	> 155	built-in area	-
10.	5	mud	plain	> 180	built-in area	-
11.	6	infill	plain	> 180	built-in area	-
12.	7	loess	plain	150	plot	Ambrosia artemisiifolia, Elymus repens, Polygonum aviculare
13.	5	infill	plain	> 150	built-in area	-
14.	5	loess	plain	> 170	common	Artemisia vulgaris, Cichorium intybus, Achillea millefolium
15.	8	loess	plain	> 200	dirt road	Cichorium intybus, Taraxacum officinale
16.	3	loess	plain	>130	arable land	Daucus carota, Petroselium crispum
17.	3	loess	plain	>95	arable land	Medicago sativa
18.	2	mud	depression	80	meadow	Lythrum salicaria, Bolboschocnus maritimus, Carex vulpina
19.	2	mud	depression	50	arable land	Zea mays
20.	5	loess	plain	>135	orchard	Brassica oleracea, Pisum sativum
21.	4	loess	plain	100	orchard	Solanum lycopersicum, Capsicum annuum
22.	10	infill	plain	>180	park	Taraxacum officinale, Lolium perenne..
23.	4	loess	plain	>120	orchard	Brassica oleracea, Allium cepa
24.	3	mud	plain	>85	pasture	Festuca pseudovina, Artemisia santonicum, Limonium gmelini
25.	3	mud	depression	>80	pasture	Potentilla reptans, Phragmites australis

The artefact content (m/m %) was determined before soil sample preparation. After drying and separation of coarse components, samples were crushed and sieved through a 2 mm mesh for further analysis. The pH (H_2O, KCl) was recorded using a digital Radelkis type pH measuring device. The carbonate content of dry soil samples, given as a percentage, was determined via Scheibler type calcimetry. The total salt content of the soils was determined by recording the electric conductivity of fully saturated soil samples. The organic content was measured after H_2SO_4 digestion in the presence of 0.33 M $K_2Cr_2O_7$. The quality of humus was given by the humus stability coefficient (K value) of Hargitai. The total nitrogen content was measured using a Gerhardt Vapodest 20 type nitrogen distilling device. The mechanical composition was determined by the yarn test of Arany. The total metal content was measured using an AAS type Perkin Elmer 3110 following a full digestion with aqua regia (Buzás et al., 1988).

According to the investigations of Szemerey (2004), the presence of mesofauna in soil is highest during the spring and autumn. Consequently soil samples to investigate soil fauna were taken in October 2006 at 10 sites [next to nine profiles (No. 1, 2, 4, 9, 11, 15, 16, 18, 22) and one other site (No. 26)] representing three zones (city, suburban, peripheral zone). Top soil (0-5 cm) samples were acquired to analyze the soil fauna, taken from two 30 x 30 cm quadrants. The extraction of tiny soil microarthropods in isopropyl-alcohol was carried out using a modified Balogh extractor within 5-6 hours of sample collection (Hoblyák, 1978). The samples were treated with a saturated NaCl suspension (Móczár, 1962) and filtered with a vacuum sieve. Extracted animals were sorted under a binocular stereomicroscope. Adult oribatid mites were identified in lactic acid to a genus level, and if possible, species was also determined, using 100x and 200x magnifications. The taxonomy of oribatid mites is well studied, so genera can be confidently identified with available identification books (Balogh and Balogh, 1992; Weigmann, 2006). Collembolans were identified to families under a binocular stereomicroscope following Bellinger's online identification database (Bellinger et al., 1996-2007) and Bährmann's identification book (Bährmann, 2000). The community structure of oribatid mites was determined on the basis of abundance. Abundance means the number of adult individuals in each taxon, and provides data on the distribution of mites in a given amount of soil sample.

The diversity of mesofaunal communities was also determined, meaning that the number of taxa (genera) was counted in a given amount of soil sample. The structure of oribatid mite communities was described with the genus dominance index, calculated with the help of the following following formula (Hoblyák, 1978):

$D= s/S*100$

s: Number of individuals belonging to a given genus in the sample.
S: Summed number of individuals of all genera in the sample.

To compare the genus composition of oribatid mite communities located in the city, suburban and peripheral zones, we used the Sørensen index (Mátyás, 1996). The value of the index ranges between 0 and 1, depending on the presence of common taxa (here genera).

$Cs=2*c/(A+B)$

c: Number of common genera.
A, B: All genera in the given samples.

Collembolans were classified into four superfamilies, each corresponding to a major ecomorphological group. The abundance of each superfamily was determined in the three different urban zones.

The measured data were processed and evaluated by EXCEL 2003 and SPSS 11 for Windows. In order to separate the anthropogenic and natural horizons within the individual soil profiles, we applied a discriminant analysis (DA). The goal of the analysis was to discriminate the groups via a linear combination (so-called discriminant function) of variables typical of the soil horizons, and using these equations to predict the future location of new samples (ungrouped horizons) within the classification (Ketskeméty and Izsó, 2005; Barczi et al., 2006).

Results

Physical and chemical properties

First, the physical and chemical properties that can indicate human impact were examined in the Szeged soils. These were chosen from diagnostic properties of urban soils as provided by Hollis (1992). The main question was whether these physical and chemical properties could indicate urban influence in the soils of Szeged as well. We also assessed the degree and way that the good indicators reflect anthropogenic effects on urban soils.

Artefacts

The average artefact content of soil profiles in Szeged ranged between 0.0 and 23.7%, with a minimum value of 0.0% and a maximum value of 63.0% (Table 2). Eleven of 25 profiles contained no artefact at all. Some of these profiles (No. 16, 17, 18, 19, 24, 25), originating from the most peripheral parts of the city, represent original genetic soil types, so the lack of artefacts is due to insignificant urban activity. For the following reasons this parameter was not present in three additional profiles originating from small orchards situated on the outskirts (No. 20, 21, 23). On the one hand, these profiles are in the surroundings of Szeged, which is free of infilling materials, so these original soils have not been altered by urban disturbance. On the other hand, exposing the upper horizons of these profiles in small orchards to human impact (e.g. intensive irrigation, nutrient enrichment) can charge certain properties (e.g. humus concentration and quality) but have no effect on the artefact content.

Profiles with very few (0-2%) or few artefacts (2-5%) are either found in the surroundings of the city, where the thickness of the infill is relatively negligible (profiles No. 10, 14, 15) or downtown where the infill might be considerable but of higher quality, thus lacking artefacts (profiles No. 1, 5, 13). These profiles either contain a considerable number of artefacts in some of their horizons, or in each horizon a small number can be observed. Profiles either partly or fully containing infill (No. 3, 8, 9, 11) can be placed in the category common (5-15%) (Fig. 2, No. 8 profile). Profiles containing a large number of artefacts (15-40%) are entirely composed of artificial infill. Thus the minimum and maximum values and the standard deviations are also striking for these profiles (No. 4, 6, 12, 22). For these profiles, the recorded amount of artefacts is considerable in each identified horizon (Fig. 2, No. 22 profile). Of this type, only No. 22 is located in downtown areas, whereas profiles No. 4, 6, and 12 are from the outskirts. Consequently, the amount of artefacts does not decrease towards the city margins because this property instead changes due to "point" factors, rather than regional factors (FAO, 2006).

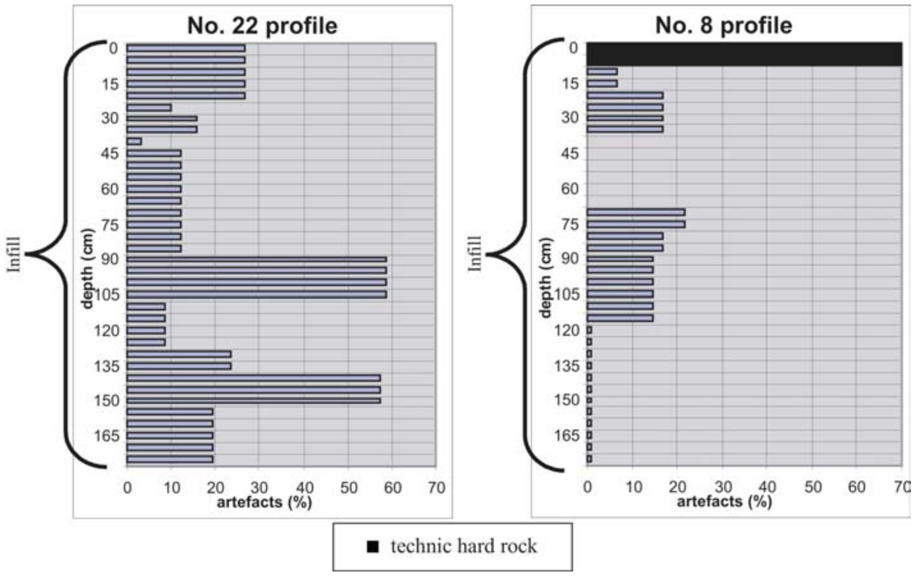

Fig. 2: Artefact content of some studied profiles.

Mechanical soil types

The mechanical soil type of profiles with original genetic soil horizons corresponds to the given genetic soil type. The mechanical soil types of Fluvisol, Vertisol, Solonetz soils are clay and heavy clay, whereas for the Phaeozem soil type, clayey mud is typical. In some profiles (No. 7, 10, 14) located in the surroundings of the city, the original soil horizons may remain. Even if they are covered in some cases by artificial objects, the mechanical soil types below still correspond to the original soil conditions. Towards the margin of the town, mixed profiles (No. 2, 3, 12, 15) composed of infill and original buried soil horizons can also be found. The horizons representing infill are dominated by sand, sandy mud, and mud, while those preserving the original conditions contain clayey mud. In the profiles composed of purely artificial infill (No. 1, 4, 5, 6, 8, 9, 11, 13, 22), sand, sandy mud, and mud are dominant. Naturally, in these latter profiles, the heterogeneity of infill is shown by some clay, clayey mud horizons between the sandy, sandy mud or mud layers. The abrupt textural change is mostly characteristic of artificial horizons in contrast to the gradual textural change of natural horizons. This is also an excellent indicator of human influence.

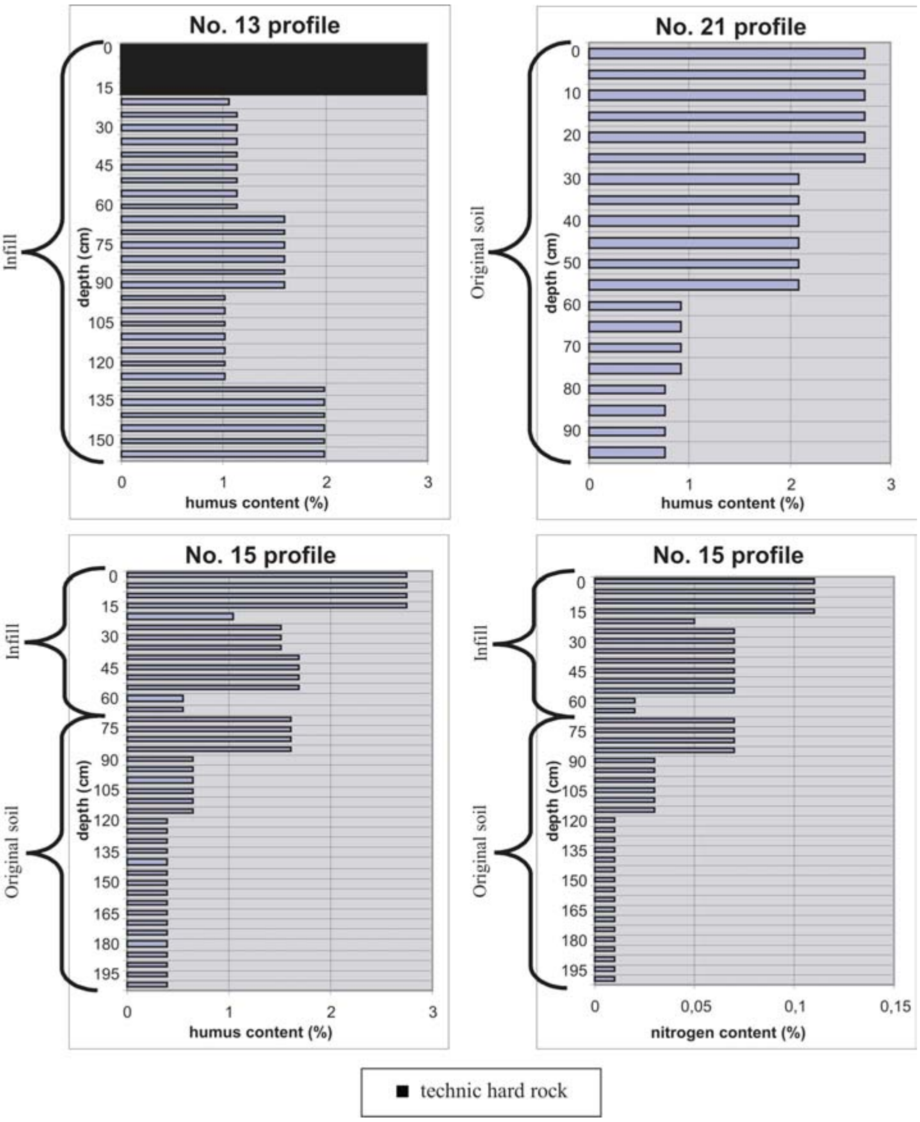

Fig. 3: Humus and nitrogen contents of some studied profiles.

Table 2: Baseline soil parameters of individual profiles.

Artefact	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Mean	4.3	0.0	6.5	23.1	3.9	23.7	0.0	10.8	15.0	4.3	5.4
Min	0.0	0.0	0.0	5.3	0.0	7.7	0.0	0.0	5.1	0.0	0.0
Max	14.7	0.0	26.6	50.7	19.4	63.0	0.0	21.6	30.9	21.4	18.0
St. dev.	5.5	0.0	6.0	19.2	8.7	21.3	0.0	8.0	11.1	9.6	6.6
Humus content											
Mean	0.6	0.6	1.7	1.7	0.7	1.5	0.8	1.9	1.4	1.6	1.4
Min	0.2	0.1	0.7	0.6	0.5	0.0	0.2	1.1	1.3	1.0	0.0
Max	1.6	1.2	3.1	3.4	1.0	3.7	2.0	3.3	1.4	2.2	2.9
St. dev.	0.5	0.5	0.8	1.2	0.2	1.6	0.8	0.7	0.0	0.5	1.1
K value											
Mean	8.0	14.4	2.6	1.9	0.6	0.6	7.0	0.8	0.6	3.9	0.6
Min	2.3	0.2	0.3	0.3	0.1	0.2	2.3	0.1	0.4	0.2	0.0
Max	20.4	29.2	7.2	6.6	1.3	1.7	9.6	1.4	1.1	9.3	1.3
St. dev.	6.9	14.9	2.2	2.4	0.5	0.6	3.3	0.5	0.3	4.1	0.5
Nitrogen											
Mean	0.02	0.03	0.06	0.05	0.03	0.07	0.03	0.07	0.05	0.08	0.06
Min	0.01	0.00	0.03	0.01	0.02	0.02	0.01	0.05	0.04	0.06	0.01
Max	0.06	0.05	0.12	0.11	0.06	0.16	0.07	0.14	0.05	0.10	0.09
St. dev.	0.02	0.02	0.03	0.04	0.02	0.06	0.03	0.03	0.01	0.01	0.03
Carbonate											
Mean	24.3	16.5	14.2	11.7	17.0	15.4	24.5	4.5	7.4	1.9	7.2
Min	9.0	2.0	2.5	8.2	1.6	11.1	10.7	1.6	6.6	0.1	2.2
Max	32.8	34.0	29.1	16.0	32.0	21.7	30.0	8.2	7.8	3.6	12.7
St. dev.	8.5	16.8	7.5	2.9	10.9	4.0	9.3	2.4	0.6	1.6	3.9
pH(H_2O)											
Mean	8.5	8.8	8.3	8.3	8.3	8.4	8.5	8.3	8.1	7.9	8.0
Min	8.2	8.7	7.9	8.0	8.0	8.0	8.3	7.7	8.0	7.8	7.6
Max	8.8	9.1	8.5	8.4	8.5	9.0	8.7	8.6	8.2	8.1	8.2
St. dev.	0.2	0.2	0.1	0.2	0.2	0.4	0.2	0.3	0.1	0.1	0.2
pH(KCl)											
Mean	8.1	7.9	7.8	7.9	7.8	7.9	8.0	7.6	7.8	7.3	7.7
Min	8.0	7.4	7.3	7.6	7.3	7.5	7.7	7.3	7.7	7.1	7.7
Max	8.3	8.1	8.0	8.2	8.0	8.1	8.2	7.8	7.8	7.5	7.9
St. dev.	0.1	0.3	0.1	0.2	0.3	0.2	0.2	0.2	0.0	0.2	0.1
Total salt											
Mean	0.03	0.05	0.03	0.02	0.11	0.06	0.03	0.04	0.05	0.05	0.05
Min	0.02	0.02	0.01	0.01	0.07	0.02	0.02	0.03	0.04	0.03	0.04
Max	0.08	0.09	0.07	0.05	0.15	0.16	0.05	0.07	0.04	0.07	0.07
St. dev.	0.02	0.03	0.03	0.02	0.03	0.06	0.01	0.01	0.00	0.01	0.01

Table 2: Baseline soil parameters of individual profiles, continued.

12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.
17.5	2.1	1.4	4.3	0.0	0.0	0.0	0.0	0.0	0.0	23.5	0.0	0.0	0.0
0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0
40.3	3.8	4.9	19.6	0.0	0.0	0.0	0.0	0.0	0.0	58.7	0.0	0.0	0.0
17.8	1.1	2.0	7.8	0.0	0.0	0.0	0.0	0.0	0.0	19.5	0.0	0.0	0.0
0.9	1.4	0.7	1.3	0.8	1.2	2.3	1.7	1.4	1.6	1.2	1.7	1.1	1.9
0.3	1.0	0.3	0.4	0.1	0.3	2.0	1.2	0.3	0.8	0.4	1.0	0.5	1.2
1.6	2.0	2.1	2.7	1.9	2.1	2.6	2.1	3.7	2.7	2.1	2.4	1.6	2.7
0.4	0.4	0.8	0.8	0.9	0.9	0.5	0.7	1.4	1.0	0.7	0.6	0.6	0.8
3.8	0.8	6.0	4.5	14.0	6.2	0.3	0.9	8.3	4.6	2.8	10.6	0.4	4.7
0.2	0.3	0.4	0.3	7.0	2.7	0.2	0.9	0.2	0.3	0.5	4.1	0.0	0.6
10.4	1.9	19.1	17.9	20.9	12.3	0.4	0.9	35	12.2	13.6	14.3	0.9	7.5
4.4	0.7	7.6	6.1	7.0	5.3	0.1	0.0	15	5.2	3.9	4.6	0.4	3.7
0.03	0.05	0.03	0.05	0.04	0.04	0.11	0.10	0.07	0.08	0.05	0.09	0.04	0.08
0.01	0.03	0.01	0.01	0.02	0.01	0.09	0.08	0.01	0.02	0.01	0.05	0.02	0.04
0.05	0.07	0.07	0.11	0.07	0.08	0.13	0.12	0.19	0.14	0.12	0.14	0.06	0.12
0.02	0.02	0.03	0.03	0.03	0.04	0.03	0.03	0.07	0.06	0.04	0.04	0.02	0.04
25.6	9.7	23.4	14.2	6.3	17.2	4.0	3.2	18.4	19.6	10.1	1.2	9.0	0.9
10.2	3.3	20.1	2.0	0.5	4.1	2.9	2.8	8.1	2.9	3.0	0.3	1.6	0.2
37.7	16.9	29.5	28.3	14.8	32.4	5.1	3.5	33.1	40.2	21.7	2.3	23.6	1.9
9.5	5.9	3.7	9.4	7.5	14.3	1.6	0.5	11.0	17.4	6.7	1.0	12.7	0.9
8.5	8.5	8.3	8.3	8.2	8.3	8.3	8.0	8.1	8.4	8.1	7.7	9.7	7.7
8.2	8.0	8.1	8.0	8.0	8.1	8.1	7.8	7.7	7.9	7.9	7.6	9.3	7.3
8.8	8.8	8.5	9.1	8.5	8.2	8.5	8.1	8.7	8.9	8.4	7.8	10.0	8.0
0.2	0.4	0.1	0.3	0.3	0.3	0.2	0.2	0.5	0.4	0.2	0.1	0.4	0.3
8.1	8.1	7.8	7.8	8.0	7.9	7.5	7.3	7.6	7.6	7.8	6.9	8.7	6.9
7.9	7.7	7.7	7.5	7.8	7.6	7.4	7.2	7.3	7.3	7.4	6.7	8.2	6.8
8.4	8.3	8.0	8.2	8.4	8.2	7.5	7.3	7.9	7.9	8.2	7.1	9.0	7.1
0.2	0.3	0.1	0.3	0.3	0.3	0.0	0.0	0.2	0.3	0.3	0.2	0.4	0.2
0.07	0.08	0.04	0.04	0.00	0.01	0.08	0.03	0.02	0.03	0.06	0.03	0.35	0.07
0.05	0.04	0.02	0.01	0.00	0.04	0.08	0.03	0.02	0.03	0.02	0.02	0.28	0.03
0.1	0.14	0.06	0.08	0.01	0.01	0.09	0.04	0.03	0.04	0.11	0.04	0.48	0.15
0.02	0.04	0.01	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.11	0.06

Humus content

The average humus content of the profiles is between 0.6 and 2.3%, with a maximum of 3.7% and a minimum of 0.0% (Table 2). If considering average values, only one profile (No. 18), developed on a natural Vertisol, showed a normal humus content (2-4%). Some profiles can be classified as having extremely poor humus content (<1%), while the majority have poor humus content (1-2%). Profiles No. 1 and 5 have extremely poor humus content, exclusively containing infill in the downtown area, as do the profiles (No. 2, 7, 12, 14) with slight amounts of infill on the outskirts. For outskirt profiles, the natural tendencies toward humus decrease resulted in low values. The remaining 17 natural and artificial profiles fall in the category of poor humus content. However, Fluvisols with their higher humus contents are slight outliers from the category poor. For the profiles without artificial cover, especially in the surroundings of the city, the recorded average humus content is somewhat higher due to an initiation of humification in the topsoil.

It might be more important to study the distribution of this parameter along the profiles, as it clearly shows the degree of human impact. Along natural profiles the humus content is congruent with the original genetic soil type; it tends to gradually decrease downwards towards bedrock (Lorenz and Kandeler, 2005). This tendency was found in profiles located in the surroundings of the city. The same can be observed along profiles showing only a slight disturbance (Fig. 3, No. 21 profile). Conversely, the humus content tends to display irregular fluctuations in those profiles that are fully composed of artificial infill, depending on the humus content of the layers used (Fig. 3, No. 13 profile). However, we have come across mixed profiles embedding considerable amounts of infill material and buried soil horizons as well. For these the tendency for the humus content is congruent with the characteristic of natural soils from the appearance of the A horizon of the original buried soil (Fig. 3, No 15 profile) (Sponagel et al., 2005).

Total nitrogen content

The significant alteration of physical, chemical and biological properties of urban soils changes the nitrogen cycle of these soils (Pulford, 1991; Beyer et al., 1995; Craul, 1999). Thus, besides determining the humus content as a complementary analysis, we also measured the total nitrogen content of the soil samples. The average nitrogen content of the profiles is between 0.02 and 0.11%, with a maximum of 0.19% and a minimum of 0.0% (Table 2). The amount of nitrogen in soils is primarily determined by the type and intensity of microbial activities. Consequently, the highest nitrogen values are recorded in those horizons where biological activity is the strongest and the largest amount of humus is produced (Stefanovits et al., 1999). The distribution of nitrogen along the studied profiles shows similar tendencies as the humus. The nitrogen content of the organic matter in soils is relatively constant. Thus, infilled horizons represent a fluctuating nitrogen content, while natural horizons have the characteristics of the genetic soil types (Fig. 3, No. 15 profile).

Besides the distribution of nitrogen along a profile, it is also important to evaluate quantitative differences. Most profiles fall in the category of extremely poor nitrogen content (<0.05%), while profiles with higher humus contents can be classified in the category of poor nitrogen content (0.05-0.10%) (Stefanovits et al., 1999).

Total salt content

The average of profile No. 24 on Solonetz fell in the category moderately saline. The horizons of the other profiles were either free of salt (<0.05%) or slightly saline (0.05-0.15%) (Stefanovits et al., 1999). Regarding salt content, no differences can be identified between natural and artificial soil horizons because both types (anthropogenic and natural) are free of salt and slightly saline. Therefore the total salt content has not increased in the soils of Szeged due to intensive human activities (Table 2).

Qualitative analysis of the humus

In practice it is important to know the ratio of well-humified, dense humus components composed of larger molecules that serve as primary agents in establishing the structure of the soil and its nutrition content to organic components that are not bonded to calcium and are less humified. This ratio is clearly depicted by the K value, described earlier. Average K values were between 0.3 and 14.4 with a minimum of 0.0 and maximum of 29.2, indicating significant differences among profiles (Table 2).

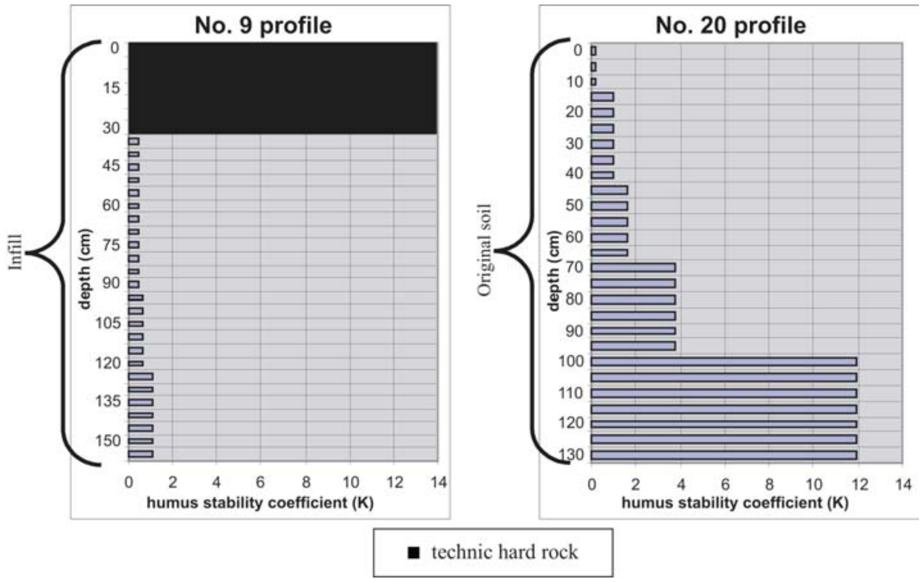

Fig. 4: Humus quality of some studied profiles.

Since the urban soils in downtown Szeged are “young” soils in contrast to the natural soils in surroundings of the city, they have not had enough time to form good quality humus. Consequently, horizons with considerable artificial infill are characterized by very low K values, indicating the prevalence of raw humus components; fulvic acids not yet subjected to humification (Fig. 4, No. 9 profile). However, mixed profiles that contain remains of the original natural soil horizons have higher K values due to the dominance of high-quality humic acids at these levels. K values in the outskirt profiles show a mixed picture. For poor quality Fluvisol, Vertisol, and Solonetz soil types (Profiles No. 18, 19, 24), where hydromorphic influence inhibits the formation of good humus, K values are very low, similar to artificial infill profiles. On the other hand, good quality Phaeozem soils (Profiles No. 17, 20, 21) have significantly higher K values (Fig. 4, No. 20 profile). Considering the average values of profiles, it is obvious that either those situated in the peripheral parts of the city (excluding Fluvisol, Vertisol, and Solonetz soil types) or those containing predominantly natural soil horizons in the downtown area have the highest values. Thus, the humus stability coefficient (K) is an excellent marker of Technosols and helps discriminate between natural and anthropogenic characters.

Carbonate content, pH (H_2O, KCl)

The average carbonate content of soil profiles ranges between 0.9 and 25.6%, with a minimum of 0.1% and a maximum of 40.2% (Table 2). Considering average profile values, one (No. 12) can be placed in the category extremely calcareous (>25%). This outlier is mostly the result of the very high carbonate content of natural horizons (especially loess bedrock). However, anthropogenic horizons are also characterized by very high carbonate values (Fig. 5, No. 12 profile). Thirteen heterogeneous profiles can be classified as highly calcareous (10-25%). Profile No. 17, which represents this type, is located in the surroundings on a Phaeozem original genetic soil type. Profiles No. 20 and 21 are located in orchards of the outskirts and are developed on Phaeozem soils free of infill.

Some further profiles (e.g. No. 7 and 14) of highly calcareous character have loessy bedrock as a significant source of high carbonate content. These profiles are located in the suburbs, in the surroundings of the city on a Phaeozem and represent a mixture of natural soil horizons and artificial infill. In such profiles there is a gradual increase in carbonate content towards the bedrock from the first natural soil horizon downward (Fig. 5, No. 12 profile). The reason for this is the leaching of carbonate phases from the upper soil horizons and the accumulation of these phases in the underlying layers or the bedrock itself.

The remaining half of highly calcareous profiles is composed of fully artificial infill. Here, either the considerable quantity of carbonate-rich artefacts or the carbonate-rich infill horizons present in individual profiles are responsible. On the other hand, some profiles (No. 8, 9, 11, 13) containing artificial infill have lower carbonate content. These and the natural profiles (e.g. No. 16, 18, 19, 24) with relatively lower carbonate values form the category moderately calcareous soils (2-10%). Two profiles representing Fluvisols fall in the category of slightly calcareous soils (0-2%): profile No. 23, originating from an orchard, and profile No. 10, composed of natural soil horizons with the exception of a surface artificial object. As a result of regular flooding by an adjacent stream, only the uppermost horizons of this profile contain aerated carbonate. Futhermore, profile No. 25 (on Vertisol with slight human impact) can also be placed in this latter category (FAO, 2006).

The averages of the pH(H_2O) are between 7.7 and 9.7 with a minimum of 7.3 and maximum of 10.0. The pH(KCl) averages are between 6.9 and 8.7, with a minimum of 6.7 and maximum of 9.0 (Table 2). Based on the average values of pH(H_2O), only profile No. 24 can be classified as a strongly alkalescent soil. All the other profiles fall on the transitional line between slightly alkaline and alkaline soils. The close correlation between recorded pH values and carbonate content is obvious: a high carbonate content results in large pH values. Thus the observed fluctuations of carbonate content within the studied profiles are congruent with the pattern observed for pH values (Fig. 5, No. 12 profile). The lowest pH(H_2O) averages were experienced on Fluvisols (profile No. 10, 23), with very little carbonate content. The alkaline profiles were located on Phaeozem-containing infill material with considerable carbonate content and buried soil horizons with very significant carbonate content. The loessy bedrock of buried soils could further increase the pH average. Some profiles can also be put in this group, if the infill was highly calcareous. The values of pH(KCl) are always lower than those of pH(H_2O). However, the tendency visible for pH(H_2O) matched that recorded for pH(KCl) (FAO, 2006).

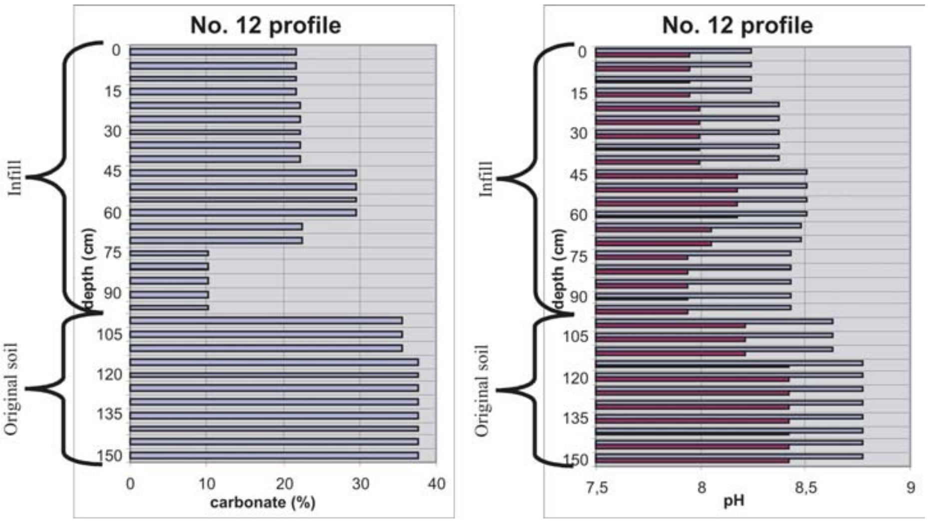

Fig. 5: Carbonate content and pH of a studied profile.

Heavy metals in topsoils and along some profiles

After evaluating basic soil parameters, it is highly recommended to determine the concentration of heavy metals, which can clearly indicate human impact, and to identify their origin. Samples were taken from the topsoil of each profile and in some selected locations from every horizon.

One crucial question when investigating urban soils is the origin of toxic metal. We applied the enrichment factor (EF) given by Rosenkranz (1991) to identify the metal origin. According to Rosenkranz, the ratios of heavy metal concentrations recorded in the fine (less than 2 mm) and coarse fractions (above 2 mm) clearly reflect the artificial or lithogenic origin. When the ratio of element concentrations for the fine and coarse components are taken to get the EF, and the factor values are around 1 or slightly below it, then the elements have an unambiguously natural origin, reflecting the element composition of the bedrock. Conversely, when this factor is greater than 1, the enrichment of elements must be from another source, indicating pollution (Hindel and Fleige, 1989). We were only able to determine the EF for topsoils contained a sufficient amount of coarse material. Consequently, the EF values of nine topsoil samples, especially those with slight disturbance (e.g. 16, 17, 18, 19), could not be determined owing to the lack of coarse material. However, for the remaining 16 topsoil samples, the EF(Zn) value is always greater than one, and the EF(Pb) value with one exception is greater than 1. Furthermore, the EF(Cu) and EF(Ni) values are also above 1 in most of the samples. As most of the EF(Zn), EF(Pb), EF(Cu) and EF(Ni) values are above 1, the metals have an anthropogenic origin. Conversely, the EF(Cr), EF(Co) and EF(Cd) values (around 1) indicate a lithogenic origin for these elements. Note that the topsoil of profile No. 3, located close to a road with heavy traffic, showed extremely high EF values, which exceed 1 several times, suggesting a strong human influence. Due to the above profile, the average EF values of anthropogenic metals (1.9-7.2) are significantly increased, whereas the average EF values of lithogenic metals range between 0.7 and 1.2 (Table 3).

Apart from identifying the origins of heavy metals, we also compared the metal concentrations in the topsoil samples with the B threshold limit value in the valid legal decree[2]. It seems likely that the anthropogenic metals mostly originate from urban traffic, as the light and food industries, dominant in Szeged, is not responsible for such concentrations. Consequently, the concentrations of anthropogenic Zn and Cu are high near avenues, ring roads and junctions with heavy traffic, and much lower in topsoils located close to roads with low traffic or where the traffic is high, but the soil is covered by dense vegetation. However, anthropogenic pollution by Ni, Cr, and Cd seems to be most significant in the orchards of the outskirts and in agricultural areas in the surroundings of the city. In these areas, intensive agriculture may be responsible for the higher concentrations, as most of the Cd, Ni, Cu, Zn, and Cr likely gets into the soil with compost, sewage sludge, organic and phosphorus fertilizers, which are all used to increase production (Alloway, 1990; Fergusson, 1990).

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[2] 10/2000. (VI. 2) KöM-EüM-FVM-KHVM collective decree on the threshold limit values for subsurface waters and their geological reservoirs.

After quantitative evaluation of the elements, congruent with the proposal of the World Reference Base for Soil Resources (IUSS Working Group WRB, 2007), the profiles where the concentration of any metal element exceeds the limit values in the topsoil were marked by the suffix toxic (Table 3).

Table 3: Concentrations and EF values for metals of the studied topsoils.

	Co	**EF(Co)**	**Cr**	**EF(Cr)**	**Cd**	**EF(Cd)**	**Pb**	**EF(Pb)**	**Zn**	**EF(Zn)**	**Cu**	**EF(Cu)**	**Ni**	**EF(Ni)**	**Suffix qualifier**
1.	2.2	0.3	43.9	1.1	0.3	0.5	52.1	7.8	136.8	6.0	35.8	4.9	29.4	1.4	
2.	2.2	0.2	69.2	1.4	0.3	0.4	39.5	2.2	**211.9**	6.3	57.4	7.3	**43.7**	2.8	**toxic**
3.	3.0	0.8	57.7	1.8	0.3	0.5	44.8	**68.4**	**202.5**	**15.4**	47.4	**14.9**	38.0	**3.0**	**toxic**
4.	0.2	0.0	47.9	0.8	0.3	0.5	22.7	3.1	185.1	9.4	35.9	3.5	30.4	5.8	
5.	3.5	1.2	40.8	0.6	0.4	0.6	43.4	3.6	**207.6**	4.7	53.3	4.2	24.0	0.9	**toxic**
6.	3.6	0.8	44.0	1.0	0.3	0.5	36.0	0.7	187.8	4.6	40.1	2.7	33.5	1.1	
7.	3.5	0.3	48.4	0.8	0.4	0.6	36.6	1.2	**219.0**	1.4	**88.2**	1.6	35.0	1.4	**toxic**
8.	5.0	0.7	54.0	0.8	0.4	0.7	32.3	2.8	195.9	4.6	68.6	1.7	28.3	0.9	
9.	8.5	3.2	53.3	0.8	0.6	0.9	32.2	1.6	199.7	3.2	27.9	0.8	16.6	0.6	
10.	1.5	0.5	56.2	1.3	0.4	0.7	34.9	2.3	**205.1**	4.3	35.2	0.4	33.9	1.3	**toxic**
11.	2.5	0.5	67.1	0.2	0.5	0.8	**135.9**	2.6	**227.8**	3.0	51.7	0.1	29.3	1.3	**toxic**
12.	5.7	0.6	52.9	1.0	0.5	0.8	54.1	3.9	**212.7**	2.8	36.1	1.9	35.9	1.6	**toxic**
13.	4.6	0.7	62.2	1.3	0.5	0.8	53.8	1.7	155.5	1.2	33.7	1.6	40.0	1.6	
14.	3.0	0.3	54.5	1.3	0.5	0.6	23.3	1.3	187.4	3.4	25.7	1.4	33.9	2.3	
15.	5.0	1.1	51.9	1.0	0.5	0.7	44.6	1.2	**225.2**	3.3	27.2	0.9	31.1	1.6	**toxic**
16.	2.3	-	17.0	-	0.3	-	1.1	-	27.2	-	18.0	-	6.8	-	
17.	5.7	-	26.7	-	0.6	-	7.22	-	38.6	-	14.5	-	14.8	-	
18.	12.9	-	**79.7**	-	0.6	-	25.1	-	102.0	-	41.9	-	**46.3**	-	**toxic**
19.	19.1	-	**90.0**	-	0.8	-	35.6	-	125.4	-	61.6	-	**58.4**	-	**toxic**
20.	6.7	-	41.2	-	0.9	-	16.0	-	122.5	-	58.0	-	23.0	-	
21.	9.2	-	51.6	-	0.9	-	15.0	-	87.3	-	45.1	-	29.6	-	
22.	9.2	2.1	50.6	4.4	0.4	1.5	61.8	11.6	100.3	4.9	29.8	3.8	28.0	3.1	
23.	16.2	-	**84.7**	-	**1.1**	-	57.4	-	184.9	-	**86.1**	-	**52.3**	-	**toxic**
24.	8.0	-	46.5	-	0.4	-	15.5	-	60.0	-	31.9	-	25.2	-	
25.	17.2	-	**84.2**	-	0.7	-	24.0	-	110.9	-	51.9	-	**53.8**	-	**toxic**
Mean	6.4	0.8	55	1.2	0.5	0.7	37.8	7.2	156	4.9	44	3.2	32,8	1.9	
Max.	19.1	3.2	90	4.4	1.1	1.5	135.9	68.4	227.8	15.4	88.2	14.9	58.4	5.8	
Min.	0.2	0.0	17	0.2	0.3	0.4	1.1	0.7	27.2	1.2	14.5	0.1	6.8	0.6	
B value	30	-	75	-	1	-	100	-	200	-	75	-	40	-	

Heavy metals concentrations and EF values were determined along the entire vertical sections of three profiles, selected because each of their horizons contains sufficient coarse components (profiles No. 4, 6, 9). EF values of the horizons can be seen in Table 4. Similar to the topsoil results, the EF(Co), EF(Cd), and EF(Cr) of the horizons were around 1 or slightly below it, i.e. they have a lithogenic origin. Conversely, EF(Zn), EF(Cu) and EF(Pb) values of some horizons significantly exceeded 1. We emphasize that EF(Zn) values were much higher than 1 in each horizon of the three profiles. Consequently the origin of this element is primarily anthropogenic. The EF(Ni) values were mostly around 1. However, values were slightly above 1 in most of the horizons, indicating a suspected anthropogenic origin for Ni (Table 4).

Table 4: EF values of each horizons of chosen profiles.

Profiles	Depth (cm)	EF(Co)	EF(Cd)	EF(Cr)	EF(Ni)	EF(Pb)	EF(Zn)	EF(Cu)
Profile 6	0-20	0.7	0.9	1.0	1.2	0.9	2.3	1.5
	20-35	0.4	0.8	0.8	1.2	2.8	2.0	1.4
	35-50	0.4	0.7	0.7	1.0	2.1	1.9	0.6
	50-65	0.4	0.7	0.8	1.2	7.8	1.5	2.4
	70-90	0.7	0.9	1.3	2.8	2.3	1.9	0.8
	90-150	0.6	0.8	0.6	1.5	2.6	2.1	1.9
Profile 4	0-10	1.1	1.1	1.1	1.0	0.3	1.8	1.5
	10-25	0.2	1.0	0.5	0.5	1.6	1.2	0.9
	25-40	0.1	1.0	0.8	0.9	1.3	1.4	1.5
	40-60	1.1	0.8	2.1	3.5	2.4	1.6	1.2
	60-80	0.5	0.8	1.2	1.3	5.2	3.7	1.5
	80-100	2.2	0.9	2.6	15.4	6.6	6.3	4.3
Profile 9	35-65	1.9	1.1	2.2	1.9	2.1	2.3	3.8
	65-95	1.0	1.0	1.1	1.7	1.8	2.1	1.9
	95-125	1.6	1.1	1.1	1.0	1.7	2.1	1.3
	125-155	1.7	1.0	1.2	1.1	2.0	2.3	1.8

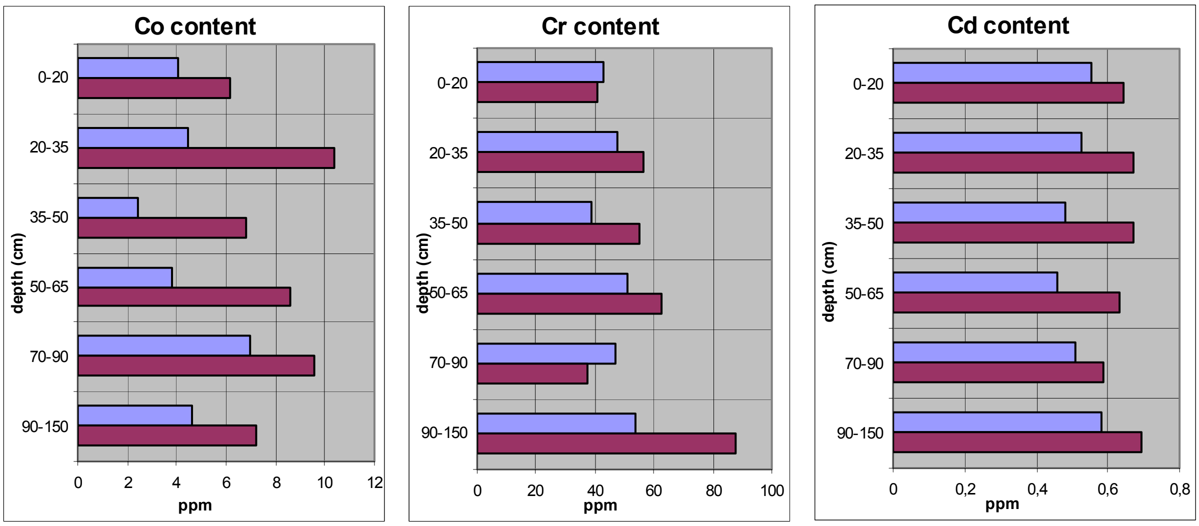

Fig. 6: Distribution of lithogenic heavy metals along a studied profile.

A detailed description of profile No. 6 is presented here as a general example. The origin of the metals can be well distinguished: the lithogenic metals (Co, Cr, Cd) tend to prevail in the coarse fraction again (> 2 mm) (Fig. 6). Conversely, the anthropogenic metals (Cu, Ni, Pb, Zn) mainly accumulate in the fine fraction (< 2 mm) (Fig. 7).

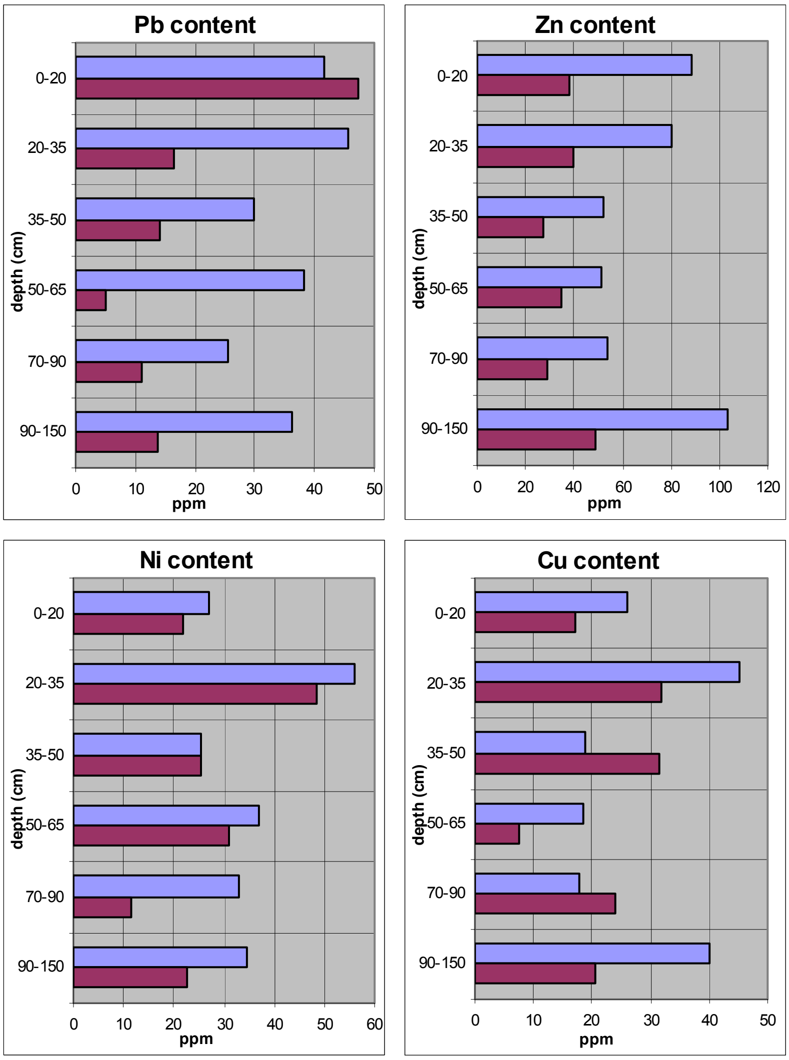

Fig. 7: Vertical distribution of anthropogenic heavy metals along a studied profile.

We also traced the vertical distribution of metals along the profiles. In undisturbed areas, metals with anthropogenic origin accumulate in the near-surface layers of the profile and their concentrations gradually decrease towards bedrock, whereas the concentrations of lithogenetic metals progressively increase downward (Thornton, 1991). This is not true for the soils composed of mixed horizons, as the continuous infilling of the city and the frequent mixing of the horizons via construction of buildings or roads often results in the embedding of unnatural materials (waste, bricks, debris) into some horizons. Consequently, the deeper horizons of such a profile are generally much richer in anthropogenic metals in proportion to the upper horizon, which has lower metal concentration, as these horizons are not autochthonous, but their components must have suffered pollution elsewhere before they were used as infill.

For example, for profile No. 6 the Pb concentration of the upper 20 cm hardly differs from that of the horizons between 50 and 65 cm or between 90 and 150 cm. When Zn is considered, another typical anthropogenic metal, then we can see that its concentration in the horizon between 90 and 150 cm is significantly higher than in the uppermost horizon (0-20 cm) (Fig. 7).

The vertical distribution of lithogenic elements also differs from that of natural profiles. These irregular vertical fluctuations in metal concentrations, indicating human influence, can also be observed in the other two profiles composed of highly mixed and transformed horizons**.** As a whole, the vertical distribution of metal concentrations in profiles affected by human activities shows irregular fluctuations, since each infill horizon contains a different amount of heavy metals depending on the original pollution of the applied material.

Investigation of mezofauna (oribatid mites and collembolans)

It has been suggested that the higher the soil quality, the more microarthropod groups are identified (Parisi et al., 2003). This was formulated as QBS (i.e. "Qualità Biologica del Suolo," i.e. Biological Quality of Soil). We followed this concept in our study, except we analyzed only the most abundant mesofaunal elements: oribatida ("box mites") and collembola (springtails). Statistical analysis was omitted since it requires repeated samplings for at least 1-2 years. The results provide a rapid and robust tool for soil science to evaluate the biological activity of urban soils. Oribatid mites and collembolans were found at each sampling point, but the numbers of individuals belonging to the different taxa were very different.

The collected 2744 adult oribatid mites belonged to 54 taxa, of which 40 were identified to the species and 14 to the genus level. Approximately 10% of the hungarian oribatid fauna were recorded in the samples of Szeged and its peripheral belt. This number is not too low compared to the values of a natural deciduous forest, rich in oribatid mites. Macropylina, Brachypilina (Gymnonota), and Brachypilina (Poronota) provided 12.9%, 40.7%, and 46.4% of the identified adult mites, respectively.

In the city zone eight genera were found, all with a very low abundance (52 sp./m^2). The number of city zone genera was only 15% of the total genus number found in this study. Although this zone is the most disturbed and polluted, a very rare mediterranean species (*Lohmannia turcmenica*, Bulanova-Zachvatkina, 1960), a special wetsoil mite (*Scapheremaeus palustris*, Sellnick, 1924), and an as yet undefined Oppiinae species were all found here. These rare species did not appear in other parts of the study area. Due to the low number of specimens, only two samples (No. 1, 22) were suitable for calculating the dominance index. In this zone, Rhysotritia was the absolute dominant (90% and 40.7%) and Scheloribates was the characteristic genus (Table 5).

Table 5: Dominant and characteristic genera of oribatid mites at different urban zones. The genera presented are those whose proportions were above 10%.

Urban zone	City				Suburban			Natural		
Sample No.	1	11	9	22	2	4	15	18	16	19
Dominant genus	Rhysotritia 40.7%	-	-	Rhysotritia 90.0%	Tectocepheus 60.0%	Rhysotritia 41.0%	Zygoribatula 51.5%	Tectocepheus 17.4%	Eupelops 67.5%	Tectocepheus 60.8%
Characteristic genus	Scheloribates 34.6	-	-	-	-	Scheloribates 33.0%	Ceratozetes 28.1%	Eupelops 12.9%	Tectocepheus 31.1%	-

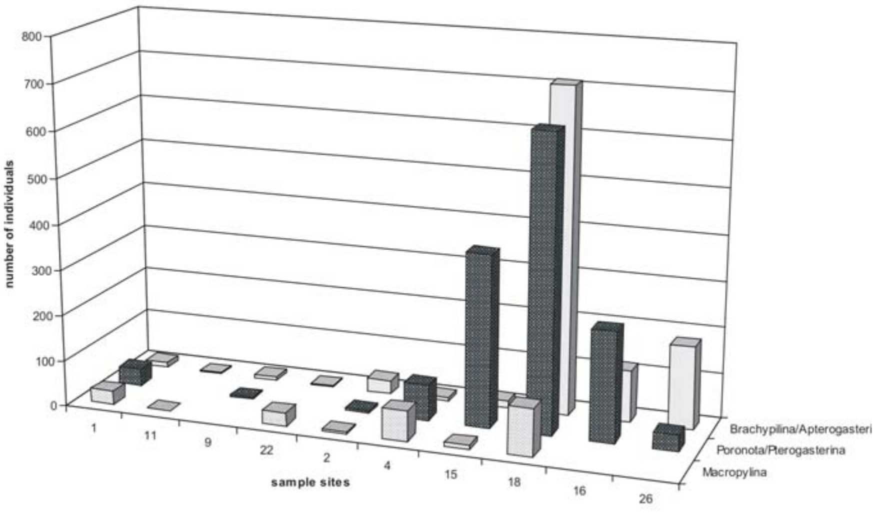

Fig. 8: Number of oribatid mites for major taxonomic groups at each sample site.

The suburban zone was unambiguously different in terms of specimen density and taxon diversity (Fig. 8). Twice as many genera (20) were found in this intermediate or transitional area as in the city zone, and the values of abundance were an order of magnitude higher (657 sp/m^2). The community structure of the oribatid mites was very heterogeneous in sites in this zone. Heterogeneity is clear from the fact that each site differed in terms of both the dominant and characteristic genera (Table 5). Community structures indicate a transition between the city and the peripheral zone. This is also suggested by the fact that both the typical genera of the city and the peripheral zone were represented here by high individual numbers. Towards the peripheral zone, taxon diversity gradually increases. Members of the Macropylina group (Rhysotritia, Eniochthonius, Nothrus) appear with relatively high individual numbers, and different kinds of Zygoribatula and Oppiidae (Dissorrhina, Neotrichoppia, Oppiella, Oppia, Ramusella) genera also occur. The number of genera (Eniochthonius, Belba, Dorycranosus, Suctobelba) recorded exclusively in this zone approached that found in the peripheral zone.

The oribatid mite density in the peripheral zone with close to natural habitats was much higher than in the former zones. In fact it is an order of magnitude higher (2252 sp./m^2) than the density determined in the suburban zone. This zone had the highest number of taxa: 44% of the total genus number. However, this is not a dramatic difference as compared to the suburban zone. The highest number of individuals, 53% of the total number, was also identified here. Figure 8 clearly shows that the three peripheral zone sites had great heterogeneity both in terms of specimen number and community structure. Note that the abundance and heterogeneity indices of samples No. 16 and 26 were significantly lower than those of sample No. 18. Soil type, the absence of vegetation cover, and the type of agricultural cultivation could be responsible for the development of the poor community structure similar to that found in the city. For sampling site No. 16, it is possible that the low moisture content of the sandy topsoil and sparse vegetation produced unfavorable conditions for oribatid mites. The dense vegetation cover at sample No. 18 was much more preferable for these animals. Nevertheless, samples of this zone with lower genus number were still more diverse in terms of Poronota and Brachypilina (Poronota) groups than any city zone samples. Depending on the type of habitat, Eupelops and Tectocepheus were the dominant genera (Table 5).

A similarity analysis based on the Sørensen index showed that there were more common genera in the suburban and peripheral zones (C_S=0.50) than in the city and suburban (C_S=0.34) or the city and peripheral (C_S=0.26) zones. This reflects the extreme character of the city zone.

Over 2060 collembolan individuals were identified and classified into four superfamilies: Entomobryoidea, Isotomoidea, Sminthuridoidea, Hypogastruroidea. Most of the collembolans represent the Entomobryoidea superfamily, while the second most abundant group was Isotomoidea, with almost a third of the total individual number. The two remaining groups had low representation, altogether providing 13% of the total. About 77% of the collembolans originated from sampling sites of the suburban zone, while the peripheral and city zones provided only 18% and 5% of the collembolans, respectively. The suburban zone was especially interesting as each ecomorphological group had the highest individual number here (Fig. 9). Note that the Entomobryoidea group was much more common than the others, as its members were identified at all sampling sites. The most sensitive group was Hypogastruroidea, the members of which were collected in large numbers only in the suburban zone (sample No. 4). The presence of all four ecomorphological groups showed its higher diversity, which indicated less disturbance in this zone.

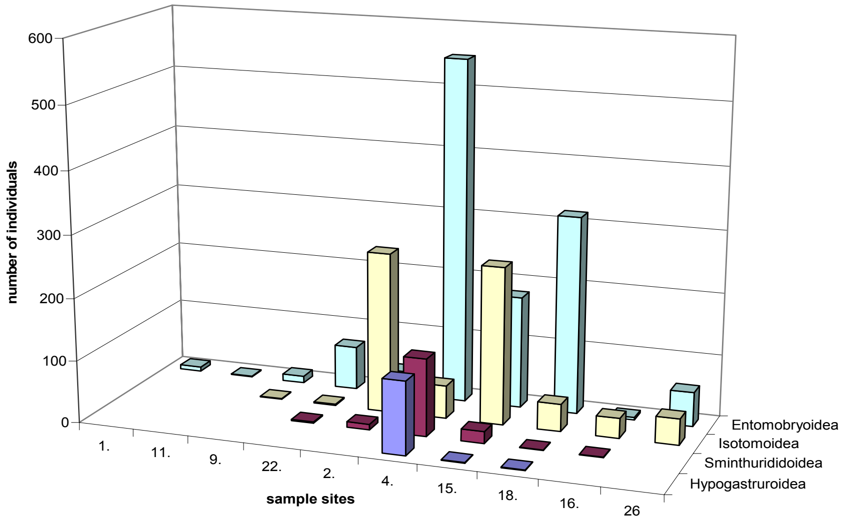

Fig. 9: Number of collembolans from major taxonomic groups at each sample site.

Prior to the mesofaunal investigation, our basic hypothesis was that the number and abundance of taxa would increase from the city towards the semi-natural habitats of the peripheral zone. Instead, the lowest abundance values were experienced in the city zone, producing numbers an order of magnitude lower than elsewhere. There was a great difference between the taxon diversity of oribatid mites in the city and the suburban zone, while the taxon diversity in the suburban and peripheral zones was similar. The low abundance in the city can be related to high air and soil pollution, habitat isolation, and low moisture content of the soil (Weigmann and Kratz, 1986).

However, the mesofauna in the more polluted and disturbed habitats of cities are obviously more random (Erhard and Szeptycki, 2002). This could be the reason that we found three peculiar species in the city zone of Szeged. The diversity of dominant species was the greatest in the suburban zone. This fact and high individual numbers suggest that the intermediate zone is a relatively good habitat. Based on the dominant oribatid mite species of the suburban zone, the transition from the barren city to the heterogonous peripheral zones could be considered continuous. The high individual and genus numbers of Gymnonota and Poronota taxa in the suburban and peripheral zones suggests a more stable oribatid mite community. The abundance pattern of collembolans corresponds well to that of oribatid mites. The diversity and abundance of collembolans were the lowest in the city zone. It seems that collembolans accumulate in suburban soils, in contrast to oribatid mites, which are more abundant in peripheral soils.

Differentiation of natural and anthropogenic horizons using discriminant analysis.

In addition to surveying diagnostic properties, classifying individual soil horizons according to their natural and anthropogenic origins was also considered important. For this purpose, we used horizons of true anthropogenic and natural origins. Two groups were established with the help of field observations, our analysis of chemical and physical properties, and maps showing the thickness of artificial infill in the city. The category of artificial infill (41 samples) was marked as group variable 1 and that of the original soil (32 samples) was marked as the group variable 2. Samples of uncertain origin were marked as ungrouped (Table 6). The undoubtedly natural horizons of profile No. 16 were excluded from the statistical analysis, since they would mislead the classification process due to their low humus and nitrogen contents, as well as sand mechanical soil type, which would have indicated an anthropogenic origin.

Table 6: Established membership of horizons of some studied profiles.

Horizons	Depth (cm)	Actual Group	Predicted Group	Discriminant Scores
15/1	0-20	1	1	-1.785
15/2	20-25	1	1	-0.033
15/3	25-40	1	1	-0.747
15/4	40-60	ungrouped	1	-1.152
15/5	60-70	ungrouped	1	-0.972
15/6	70-90	ungrouped	1	-0.147
15/7	90-120	2	2	2.574
15/8	120-200	2	2	2.476
20/1	0-15	ungrouped	1	-2.421
20/2	15-45	ungrouped	1	-0.435
20/3	45-70	ungrouped	1	-0.485
20/4	70-100	2	2	1.310
20/5	100-145	2	2	2.175
23/1	0-30	ungrouped	2	1.080
23/2	30-60	2	2	2.024
23/3	60-80	2	2	2.747
23/4	80-100	2	2	1.706

The predictor or input variables displaying normal distribution were the recorded parameters of the individual horizons (carbonate content, pH value, humus content and quality, total salt content, nitrogen content, artefact content, and mechanical soil types). By linear combination of these input variables, with the help of the so-called discriminant function (0.33 × artefact - 0.59 × humus + 1.08 × $CaCO_3$ + 1.49 × yarn), we classified the horizons of uncertain origin into suitable classes. The best discrimination was achieved by the linear combination of the amount of artefacts, yarn test values, humus and carbonate content. Using this function, the values of group 1 are negative, while those of group 2 are larger than 0.5 (Fig. 10). The results depicted in Table 7 clearly justify the differences discussed earlier in the observed parameters of the two groups. The average of the artefact content was unambiguously an important discrimination factor for identifying infill-type soils with high (15.2%) (group 2) and natural soil horizons with low artefact (0.2%) (group 1) content.

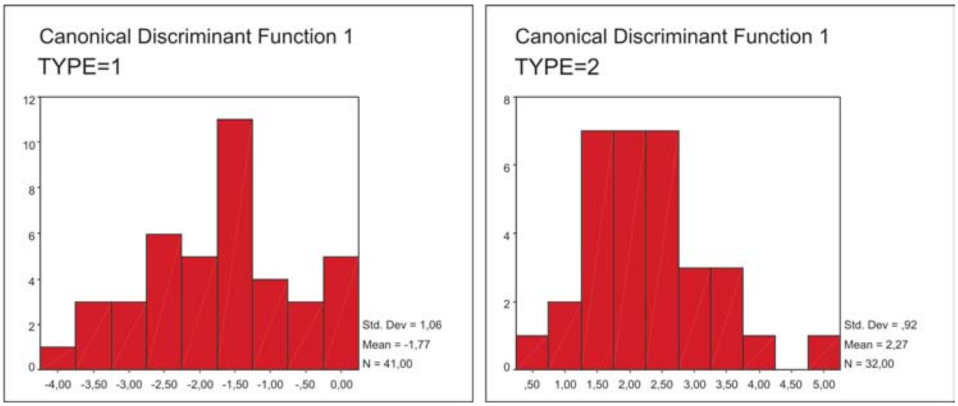

Fig. 10: Discriminant function values of groups.

Table 7: Statistical evaluation of studied diagnostic properties.

Type	Diagnostic properties		Mean	Std. Deviation
1.00	ARTEFACT	-	15.2	15.7
	HUMUS	%	1.5	0.9
	$CaCO_3$	%	9.4	5.4
	PH(H_2O)	-	8.2	0.2
	PH(KCL)	-	7.8	0.2
	NITROGEN	%	0.05	0.0
	K VALUE	-	1.9	2.8
	YARN TEST	-	38.0	6.3
	TOTAL SALT	%	0.04	0.0
2.00	ARTEFACT	-	0.2	0.9
	HUMUS	%	1.0	0.6
	$CaCO_3$	%	17.8	14.2
	PH(H_2O)	-	8.5	0.6
	PH(KCL)	-	7.8	0.5
	NITROGEN	%	0.04	0.0
	K VALUE	-	5.9	7.0
	YARN TEST	-	52.5	11.8
	TOTAL SALT	%	0.07	0.1

The mechanical soil types in the case of group 1 horizons were mainly sandy muds and muds, while horizons of group 2 were dominated by clayey muds and clays. The average humus content was generally low in both groups. However, when compared, horizons of group 1 (1.5%) showed a higher content than those in group 2 (1%). This phenomenon can be explained by the presence of infill horizons with considerable humus content as well as by the fact that profiles next to infill horizons were generally poor in humus. These former horizons tend to increase the average humus content of the profiles.

According to the average K values, indicating the quality of humus, it is obvious that the horizons with a considerable amount of artificial infill are characterized by the prevalence of poor-quality humus components (fulvic acids) (1.9). The natural horizons, on the other hand, had higher K values, indicating the dominance of high-quality humic acids (5.9). The higher nitrogen average values recorded in the natural soils are highly correlated with the average humus contents, indicating a strong bonding of nitrogen to organic matter. The average values for the carbonate content are also higher in the group of natural soils (17.8%), due to the higher carbonate content of the natural bedrock in these soils (loess). In addition, the anthropogenic horizons also had considerable carbonate content (9.4%), especially those that contained large quantities of artefacts with high carbonate content. The averages of $pH(H_2O)$ and pH(KCl) are more or less the same for the two groups.

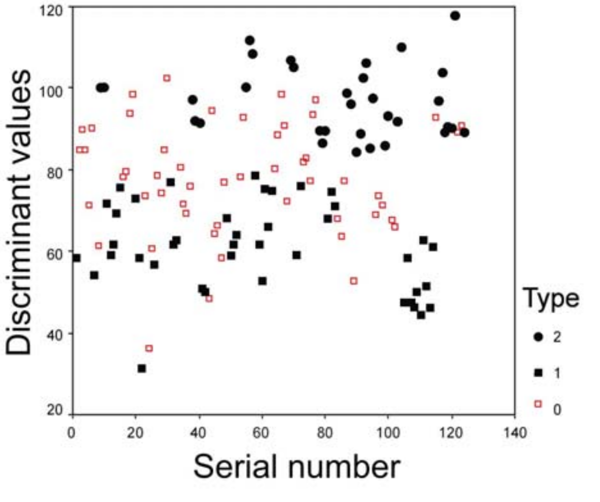

Fig. 11: Soil horizons in accordance with their discriminant values.

The differentiation of the groups (No. 1, 2, and ungrouped) can be seen in Figure 11, which shows the identification numbers of horizons on the x-axis and the values of the discriminant function on the y-axis. The clearly infilled horizons are marked by 1 and natural horizons by 2. Uncertain horizons, marked by 0, are located around them. Horizons of groups 1 and 2 can be clearly delineated on the figure: two separate clouds of data points can be identified corresponding to the samples of groups 1 and 2. The discriminant function values of the natural horizons are located in a narrower zone (values between 85 and 120), indicating the similarity and homogeneity of properties of these horizons. However, the discriminant function values of the anthropogenic horizons (group 1) are located in a wider zone. This suggests marked heterogeneity in the properties of these horizons.

An imaginary line can be drawn between groups 1 and 2, along which the horizons falling in the category “ungrouped” can be classified into them. Of the 51 samples identified as ungrouped, 100% were correctly classified; 28 were placed in group 1 and 23 in group 2. The significance of the identification of the correct group membership from a pedological point of view lies in the fact that a clear borderline can be established between the natural and anthropogenic soil layers for each individual profile. However, there were some horizons that were plotted to the natural group during analysis, while on the basis of infill maps and diagnostic properties they were considered infilled. The reason for this is that some of the infill had sufficient time and suitable soil factors to undergo pedogenesis. As a result, some artificial horizons have diagnostic properties that appear natural.

Conclusions

The evaluation of basic soil properties shows excellent indicators of urban soils and indicates in what way and to what extent they can reflect urban influence on Szeged soils. All the soil parameters mentioned except for total salt content appear to be excellent markers of human influence. This can be seen either in a change in their recorded concentration values or the alteration of their vertical distribution in the profiles. An elevated amount of artefacts, fluctuating humus and nitrogen levels, poor quality of humic materials, higher and fluctuating carbonate content, concomitant variance in the pH, and modified mechanical properties all indicate soils affected and transformed by human activities.

We found that the heavy metal concentrations of the studied topsoil exceeding the B threshold limit value clearly indicated the human influence on the urban area. The B value was exceeded partly by topsoils situated in the downtown area near roads with heavy traffic, and partly by samples from orchards on the outskirts, where intensive cultivation may be responsible for the higher concentration. These profiles received the suffix toxic, which is an important suffix qualifier in the classification of Technosols in the World Reference Base for Soil Resources (IUSS Working Group WRB, 2007). In addition to our quantitative evaluation of the metals, we also needed to determine their origin to assess the intensive urban (especially traffic) effects in Szeged. Based on our analysis, Pb, Zn, Ni and Cu are of anthropogenic origin, while Co, Cr and Cd are of lithogenic origin, both in the topsoils and in the horizons of the three profiles studied in detail.

In addition to the physical and chemical properties of the soil, we also analyzed biological indicators. Our results greatly support those of a previous study by Magura et al. (2006), in which they found that intermediate, transitional areas between the city and the peripheries show a greater diversity than the later two. It seems that this intermediate zone is stable and heterogeneous enough to constantly provide species for the city and peripheral areas. The concentric structure of Szeged is also important, as it ensures a gradual transition between the city and the peripheral areas. Since there is no contiguous industrial zone, the intermediate area between the city and the periphery acts as a significant buffer and refuge for soil microarthropods.

Using the method of DA, we evaluated the above parameters, which enhanced our classification of the studied horizons into the categories of natural and anthropogenic. Horizons of uncertain origin were correctly assigned into these two groups using the previously mentioned parameters and the method of discriminant analysis. By separating natural and infill horizons, we could draw a discrimination line between the two groups. Consequently, based on our evaluation of diagnostic properties and the results of our discriminant analysis, four main soil types can be identified in Szeged related to the degree of human influence:

- Some of the profiles with original soil types in the peripheries of Szeged (No. 16, 17, 18, 19, 24, 25) were very slightly influenced by human activities. The diagnostic properties of these hardly show any change. Thus, they totally reflect the original genetic soil type. These profiles were classified into Phaeozem, Fluvisol, Gleyosol, Arenosol, Solonetz natural soil groups. As a result of the discriminant analysis, all their horizons were classified into group 2.
- The next class consists of the profiles experiencing some human influence (Profile No. 7, 10, 14, 20, 21, 23). The diagnostic properties of these changed slightly. These profiles originate from the outskirts where no infill occurred. As a result of the above, they are intact but are usually either covered by artificial objects (e.g. concrete) or exposed to intensive agricultural activities. This exerts negative effects on some soil parameters (e.g. humus content). Consequently, some of the upper horizons were classified into group 1, while most fell into group 2.
- Mixed profiles (No. 2, 3, 12, 15) on the outskirts fell into the category of strongly modified soils. These profiles with some natural horizons and a significant amount of infill (profile No. 2, 3, 5, 8, 12, 15) have been changed considerably by human activities. Their diagnostic parameters already show a significant variance. Consequently, most of the horizons of these profiles plotted to the group of anthropogenic origin.
- The rest of the profiles (No. 1, 4, 5, 6, 8, 9, 11, 13, 22) have been completely altered by very intensive human influence. They contain nothing but infill horizons with special features (e.g. intensive compaction, horizontal and vertical variability, usually high amounts of artefacts, anthropogenic parent material) and are generally covered by artificial objects. For these, the original genetic soil type cannot be identified at all. The diagnostic properties of these profiles have been altered the most, causing all of them to fall into

group 1. Furthermore, we found that three of the nine studied profiles were not situated in the city centre. Therefore it is not necessary for soils in this group to be located in the city centre, since local influences can overwhelm the effect of artificial infill.

Considering all the profiles, two in the city centre can be considered the most anthropogenic: No. 11 and 22. We suggest that profile No. 11 with "technic hard rock" has the least chance to experience pedogenetic processes since the horizons are covered by thick, surface artificial objects, and are thus isolated from the outside world. However, in the case of profile No. 22, with dense vegetation and without surface artificial objects, the high amount of artefacts inhibits pedogenesis.

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