Comparison of soil properties in urban and non-urban grasslands in Budapest area

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Abstract
This study focused on the physical, chemical and microbiological characteristics of soils from different grasslands in the Budapest area. Our aim was to assess the influence of anthropogenic activities on these soils by comparing three types of site: urban, green-urban and non-urban. From these sites, a total of 72 topsoil samples were collected and analysed. The results indicated that many properties of soils varied greatly between the different types of site. Urban soils had significantly higher pH, carbonate and salt content, but smaller organic carbon content than the other soils. These differences could be explained in part by the greater artefact content, as the latter was significantly correlated with most of the main soil properties. Concentrations of the heavy metals measured (Co, Cu, Cr, Fe, Mn, Ni, Pb, Zn) were generally smaller in non-urban soils. In urban and green-urban soils, Cu, Cr, Ni and Pb levels were above the natural background levels, due to anthropogenic inputs in the city. Results of microbiological analyses were controversial. According to most probable number (MPN), there was no significant difference between types of site for bacterial and fungal numbers in soil. However, dehydrogenase activity and the number of bacterial cells were larger in non-urban than in urban soils. It was also found that microbial parameters were influenced by many soil properties, for example organic matter and macronutrient (N, P, K) content of soils, the presence and amount of artefacts and metal concentrations in soil.

KEYWORDS
Budapest, heavy metals, microbial properties, urban grasslands, urban soil

1 | INTRODUCTION

Characteristics of urban soils usually differ from non-urban ones, since they are more strongly influenced directly (e.g., excavation, mixing, incorporation of man-made materials) or indirectly (e.g., atmospheric depositions, urban heat island effect) by human activities (Lehman & Stahr, 2007; Norra & Stuben, 2003). For example, anthropogenic activities can contribute to higher bulk density, pH and carbonate content of soils (Biasioli, Barberis, & Ajmone-Marsan, 2006; Jim, 1998; Nehls, Rokia, Mekiffer, Schwartz, & Wessolek, 2013; Pouyat, Yesilonis, Russell-Anelli, & Neerchal, 2007; Washbourne, Renforth, & Manning, 2012). These modifications can adversely affect many physical, chemical and biological processes...
in soil and indirectly in its wider environment. Furthermore, urban soils usually contain greater quantities of pollutants than the surrounding non-urban soils (Biasiolli et al., 2006; Wei & Yang, 2010; Yang, Campbell, Clark, Cameron, & Paterson, 2006). One of the main contaminants in these soils is heavy metals, which pose potential threats to the environment and human health (Alloway, 1995; Duruibe, Ogwuegbu, & Egwurugwu, 2007; Mónok, Kardos, & Végvári, 2019; Motuzova, Minkina, Karpova, Barsova, & Mandzhiyeva, 2014). Therefore, numerous studies have been carried out in recent years to investigate the metal content and its effects in different urban soils (Andersson, Ottesen, & Langedal, 2010; Argyraki & Kelepertzis, 2014; Birke & Rauch, 2000; Gąsiorek, Kowalska, Mazurek, & Pająk, 2017; Imperato et al., 2003; Madrid et al., 2006; Salonen & Korkka-Niemi, 2007). It is also important to note that not all soil is modified markedly by human activities within the city boundaries. There are sites (especially in suburban areas) where natural factors play a more important role in soil forming than anthropogenic factors (Lehn & Stahr, 2007; Norra & Stuben, 2003).

Although physical and chemical properties have been widely investigated, the influence of human disturbances on the microbiological parameters of urban soils is still inadequately understood. However, using microbial analyses to evaluate soil quality is highly important as soil microorganisms play a key role in many soil functions, such as nutrient cycling, organic matter decomposition and biodiversity regulation (Guilland, Maron, Damas, & Ranjard, 2018; Zhao & Li, 2013). In addition, previous studies have indicated that microbial biomass and the activity of different enzymes are sensitive to anthropogenic factors (Lehmhal & Stahr, 2007; Norra & Stuben, 2003).

The aim of this study was to assess the influence of anthropogenic activities on grassland soil in a large city. Another objective was to determine relationships between soil properties, to find out the properties which play a key role in the modification of these soils. For these purposes, we compared soil physical, chemical and some microbiological properties in three different types of grasslands (urban, green-urban and non-urban grasslands) in Budapest and in the surrounding area. We hypothesized that soil properties in human-disturbed urban grasslands clearly differ from those of green-urban grasslands which is less affected by anthropogenic activities. The city structure of Budapest is similar to many other cities in Europe; therefore, our result may be extended to them as well.

2 | MATERIALS AND METHODS

2.1 | Study area

Budapest, the capital of Hungary, is located in central Europe (47°29′N–19°03′E), with an area of 525 km² and a population of 1.75 million in 2018. The city has a humid continental climate with a mean annual precipitation of 516 mm, which mainly occurs from May to June. Average monthly temperature ranges from −4 to 1°C in January to 16 to 27°C in July. The Danube River separates the city into two parts: Buda is a hilly area, while Pest lies on the flat terrain of Pest Plain, which is part of the Great Hungarian Plain. Built-up areas occupy 52% of the territory of Budapest and it is increasing, while only 83 km² of the city is green space, parkland and forest. The area of the city has been inhabited since ancient times, and it has a long industrial history. Currently, the main emitters of polluting agents are power stations, pharmaceutical factories and chemical plants, which are mainly located in Pest.

The local dominant soil type is Phaeozems according to the World Reference Base soil classification (IUSS Working Group WRB, 2015), and the dominant parent material is loess. Soil properties may have changed in many sites due to the high degree of urbanization and industrialization in the area. However, in some sites, the soil is less affected by human activities. For these reasons, Budapest is highly suitable for our research.

2.2 | Study sites and soil sampling

All study sites were grasslands, which were located in the Pest part of Budapest or east of the city (Figure 1). Samples were collected from three types of site: urban sites (n = 7), green-urban sites (n = 7) and non-urban sites (n = 4). A site was chosen as an urban site if the following criteria are present:

1. located near built-up areas, and
2. potentially affected by one or more of the following anthropogenic activities:
   a. former use of the site; or
   b. heavy traffic or industrial activity within 100 m; or
   c. a residential area located right next to the site

Urban sites could be divided into three groups: abandoned industrial sites (n = 2), industrial sites (n = 2) and residential sites (n = 3). Abandoned industrial sites have been abandoned for more than 20 years and located in an industrial area with many different small industrial activities. Industrial sites were located near industrial parks with various factories: chemical factories, breweries and many other smaller manufacturing enterprises being found here. Residential sites were in residential areas of the city. Two of them were located next to main roads with heavy traffic, while the other residential site was surrounded by smaller roads. It should also be noted that on four out of seven urban sites, illegally dumped waste was observed.

In contrast to urban sites, green-urban sites were located near natural areas and had no heavy traffic or industrial
activity within 250 m. These sites could be divided into two groups: park sites \( (n = 3) \) and unmanaged sites \( (n = 4) \). Two of the park sites were located near small residential areas, but more than 50 m away from them, while the other park site was located between a cemetery and a forest. Unmanaged sites were located near forests or other grasslands.

Non-urban sites \( (n = 4) \) were also unmanaged, but were located outside the city, more than 19 km away from the city centre and more than 300 m away from any built-up area. These sites were chosen as control sites since they were away from any potential human disturbance.

Soil samples were collected during September–October 2018. At each site, four composite topsoil samples \( (0–20 \text{ cm}) \) were taken by mixing subsamples from ten random points. Before samplings, the herbaceous cover of the sampling points was always removed.

2.3 | Analyses of physical and chemical properties of soils

Examination of soil samples took place in the soil laboratory of the Department of Soil Science and Water Management, Szent István University. From soil samples all artefacts (e.g., concrete, bricks, cement, glass or plastic) which were greater than 2 mm in size were separated and weighed before sample preparation. Its amount was expressed as a percentage of the weight of the soil samples. Then, soil samples were air-dried, sieved to <2 mm and stored at 25 ± 2°C before use.

The texture of soils was identified by particle size distribution with a hydrometer (Van Reeuwijk, 2002). The pH was determined potentiometrically in KCl and H2O solution, 1:2.5 soil/solution ratio. Organic carbon content (SOC) was recorded by the Tyurin method (oxidation with sulphochromic acid), while electrical conductivity (EC), as a measure of the total salt content of the soil, was determined by conductometer in H2O solution, 1:5 soil/solution ratio. The calcium carbonate (CaCO3) content of the soil was recorded using a Scheibler calcimeter. In addition, the total N, ammonium lactate (AL)-extractable P and AL-extractable K contents of the samples were also measured. Most of these applied methods were based on Hungarian standards (MSZ-08-0206-2, 1978; Stefanovits, Gy, & Gy, 1999). Metal (Co, Cu, Cr, Fe, Mn, Ni, Pb, Zn) concentration in soil samples was determined after HNO3 + H2O2 digestion by atomic absorption spectrometry (AURORA AI1200 Atomic Absorption Spectrometer).

2.4 | Microbiological analysis

Microbial tests were conducted to make a more comprehensive evaluation of soil quality. For these tests, fresh and field-moist soil samples were kept at 4°C.

Most probable number (MPN) was used to quantify bacteria and fungi populations within the soil samples. It was performed by a microplate method (Reichart, 1991; Veres, Kotroczó, Magyaros, Tóth, & Tóthmérész, 2013) from 10-fold serial soil dilutions (from \( 10^{-1} \) to \( 10^{-5} \)), which were made from nutrient broth (meat extract 3 g L\(^{-1}\), peptone 5 g L\(^{-1}\),
glucose 5 g L⁻¹, NaCl 0.5 g L⁻¹, pH 7.0 ± 0.2) for the quantification of bacteria and Sabouraud broth (casein 5 g L⁻¹, meat extract 5 g L⁻¹, glucose 20 g L⁻¹, pH 5.7 ± 0.2) for fungi. After visual evaluation of the tests, MPN values were calculated using the MPN table of Cochran (1950).

Dehydrogenase activity (DHA) was measured using triphenyltetrazolium chloride (TTC) as an artificial electron acceptor, which is reduced to the red-coloured triphenylformazan by enzymatic reactions. 1 g soil sample was mixed with 1 cm³ TTC solution, and after 24 hr incubation at 30°C, the enzymatic reaction was stopped by addition of acetone to the mixture. Then, the concentration of triphenylformazan was measured with a photometer at a wavelength of 546 nm.

The number of bacterial cells (live and dead) was also determined in soil samples with a direct microscopic method. For this, 1 cm³ soil was diluted with distilled water and the number of the visible bacteria was counted on a known volume microscopic slide with a light microscope. The number of bacteria counted was multiplied with the known parameters (dilution range, slide volume, number of microscopic field of view on a slide) to determine its number in 1 cm³ soil.

2.5 Statistical analyses

Statistical analyses were carried out with SPSS 23.0 (SPSS Institute Inc. 2015). To compare the means of the results, ANOVA and Tukey’s post hoc test were applied. The normal distribution of the data was checked by Kolmogorov–Smirnov or Shapiro–Wilk test, while the homogeneity of variances was proven by Levene’s test. If data failed Levene’s test, Games–Howell post hoc test was applied instead of Tukey’s test. In addition, Pearson’s correlation analyses were also carried out between the properties of soil samples to detect if there was any connectivity between them.

3 RESULTS AND DISCUSSION

3.1 Soil main properties

The mean values, medians, standard deviations, and minimum and maximum of soil main properties are shown in Table 1, while the correlation matrix between some properties is shown in Table 2. There were significantly greater amounts of artefacts in urban soils than in the other two types of soil. One reason for this is that large amounts of construction wastes were found in abandoned industrial sites. According to previous studies, incorporation of these materials usually indicates a strong impact of human activities on the soil (Biasioli et al., 2006; De Kimpe & Morel, 2000; Lehmann & Stahr, 2007; Norra & Stuben, 2003). In addition to construction materials, glass and plastic were also found in some urban samples as well. They were present in very large

### Table 1

|                  | Artefacts, g kg⁻¹ | Sand, g kg⁻¹ | Silt, g kg⁻¹ | Clay, g kg⁻¹ | pH_H₂O | pH_KCl | SOC, % | Salt_H₂O, % | CaCO₃, % | N, % | P, mg kg⁻¹ | K, mg kg⁻¹ |
|------------------|-------------------|--------------|--------------|--------------|--------|--------|--------|-------------|---------|------|------------|------------|
| **Urban sites (n = 28)** |                   |              |              |              |        |        |        |             |         |      |            |            |
| Mean             | 132 a             | 485 a        | 312 a        | 207 a        | 7.6 a  | 7.3 a  | 2.21 a | 0.24 a      | 10.0 a  | 0.17 a | 129.7 a    | 147.7 a    |
| Median           | 124               | 490          | 315          | 180          | 7.6    | 7.2    | 2.05   | 0.23        | 10.7    | 0.17  | 138.0      | 165.2      |
| Max              | 284               | 640          | 445          | 385          | 8.3    | 7.7    | 4.34   | 0.30        | 18.5    | 0.31  | 211.1      | 191.2      |
| Min              | 36                | 290          | 204          | 108          | 7.0    | 6.6    | 0.85   | 0.15        | 2.1     | 0.07  | 63.3       | 92.0       |
| SE               | 7.0               | 23           | 14           | 15           | 0.05   | 0.05   | 0.17   | 0.01        | 0.8     | 0.02  | 8.3        | 6.5        |
| **Green-urban sites (n = 28)** |                   |              |              |              |        |        |        |             |         |      |            |            |
| Mean             | 54 b              | 575 ab       | 257 ab       | 178 a        | 7.1 b  | 6.7 b  | 4.48 b | 0.19 b      | 4.0 b   | 0.14 a | 133.1 a    | 174.1 b    |
| Median           | 58                | 554          | 270          | 170          | 7.0    | 6.8    | 4.15   | 0.20        | 4.4     | 0.12  | 117.2      | 173.1      |
| Max              | 95                | 810          | 411          | 364          | 7.7    | 7.4    | 7.03   | 0.27        | 9.9     | 0.30  | 206.1      | 222.0      |
| Min              | 13                | 305          | 99           | 79           | 6.5    | 6.0    | 2.54   | 0.14        | 0.1     | 0.05  | 64.4       | 125.8      |
| SE               | 22                | 29           | 17           | 17           | 0.07   | 0.07   | 0.24   | 0.01        | 0.6     | 0.01  | 9.7        | 5.2        |
| **Non-urban sites (n = 16)** |                   |              |              |              |        |        |        |             |         |      |            |            |
| Mean             | 24 c              | 678 b        | 224 b        | 98 b         | 6.8 b  | 6.5 b  | 3.77 b | 0.18 b      | 1.5 b   | 0.27 b | 194.5 b    | 183.2 b    |
| Median           | 25                | 645          | 230          | 95           | 6.8    | 6.4    | 3.80   | 0.19        | 1.4     | 0.26  | 181.2      | 180.7      |
| Max              | 43                | 794          | 420          | 152          | 7.2    | 7.1    | 5.83   | 0.22        | 3.4     | 0.19  | 300.4      | 145.3      |
| Min              | 8                 | 422          | 115          | 40           | 6.2    | 5.8    | 2.05   | 0.11        | 0.1     | 0.38  | 114.9      | 231.5      |
| SE               | 2.3               | 39           | 27           | 12           | 0.08   | 0.09   | 0.28   | 0.01        | 0.3     | 0.01  | 12.5       | 7.1        |

Note: Different letters mean significant differences (< .05) for different sample sites by Tukey’s or Games–Howell’s test.
quantities at one of the industrial site, which may be related to the illegal waste found there.

Particle size distribution results showed sand > silt > clay in all types of sites. Sand content of soils was larger for non-urban sites, whereas silt and clay contents were smaller in these areas. The standard deviation of these parameters was quite large for all types of sites, which could be due to the considerable horizontal variability of soils in the study area.

In urban soils, pH was significantly higher than in green-urban and non-urban soils, which also has been reported by several authors (Li et al., 2013; Pouyat et al., 2007; Zhao, Zhang, Zepp, & Yang, 2007). Higher pH for urban soils could be partly explained by the larger amount of artefacts, especially construction waste which is often very alkaline due to its large limestone content (Lorenz & Kandeler, 2006; Nehls et al., 2013; Park et al., 2010). In our study, the significant connection between artefact content and pH of soils was also confirmed by Pearson's correlation analysis (Table 2).

The content of SOC was significantly less in urban soils than in green-urban soils and non-urban soils. According to some authors, urban soils could contain large amounts of organic matter (Lehmann & Stahr, 2007; Zhao & Li, 2013); however, in our study, SOC was very small (below 1%) at abandoned industrial sites. The main reason for this may be the presence of large amounts of organic-carbon-poor artefacts in these soils. This is supported by the fact that SOC content was significantly negatively correlated \( r = -.628; p < .001 \) with the artefact content of soil samples. In addition to this, previous removal of topsoil can also lead to reductions in SOC content (Craul, 1993). It was also noticeable that soils from unmanaged sites had the largest SOC content. This is partly explained by the smaller artefact content; however, according to Li et al. (2013), removal of plant materials also leads to a smaller SOC content, as it limits carbon return to the soil.

The total salt content was significantly larger in urban soils. This parameter was correlated with other soil properties such as artefact content \( r = .590; p < .001 \) with phosphate content \( r = .441; p < .001 \) and \( \text{pH}_{\text{H}_2\text{O}} \) \( r = .414; p < .001 \) and \( \text{CaCO}_3 \) content \( r = .720; p = .005 \).

\( \text{CaCO}_3 \) content was also significantly greater in urban soils. The results are in accordance with soil pH, which means that \( \text{CaCO}_3 \) content in soils may also depend on the larger amount of artefacts (Nehls et al., 2013; Washbourne et al., 2012). Correlation analysis also supports the conclusion, as there was a strong significant correlation \( r = .745; p < .001 \) between \( \text{CaCO}_3 \) and artefact content of soils.

The highest levels of soil macronutrients (total N, AL-extractable P and AL-extractable K) were observed in non-urban soils. There are several reasons for the smaller nutrient content of urban and green-urban sites. According to Li et al. (2013), a smaller N content of urban soils may be regulated by the slow rates of N mineralization and nitrification, which can be the consequence of smaller SOC content or fewer and less diverse soil organisms. Lower P levels may be the result of reduced organic inputs, whereas lower K levels may be associated with greater \( \text{CaCO}_3 \) contents in soils (Li et al., 2013; Pouyat et al., 2007). However, in our results, only K content was correlated \( r = -.515; p < .012 \) with artefact content of soil.

### 3.2 Heavy metals in soil

The main statistical indices of metal concentrations in soil samples, as main soil properties, are shown in Table 3. It was clear that urban activities increased the metal concentrations in soil, as the mean values of the measured elements (except for Co and Mn) were significantly larger in urban samples than in non-urban ones. In urban soils, most of the heavy metals displayed wide variability in their concentrations, which reflects the variety of anthropogenic impacts. The largest metal concentrations were found at the two industrial sites; however, they were also greater than the average at a residential site, which was located near main roads. According to previous studies, industrial
and transport emissions are the main factors contributing to the accumulation of these metals in soil in other cities as well (Argyraki & Kelepertzis, 2014; Biasioli et al., 2006; Imperato et al., 2003; Wei & Yang, 2010).

The mean concentration of Cu and Pb was significantly greater in urban soils than in green-urban ones; however, there were no significant differences in the concentration of other metals. This means that although human activities are further away from green-urban sites, they are still influenced by them. According to some authors, heavy metals can travel more than 250 m (the distance from green-urban sites without heavy traffic or industrial activity) in the air, associated with airborne particulate matter, before they deposit on the soil surface, which would explain our results (Morselli et al., 2003; Steinnes & Friedland, 2006). Cr, Ni and Zn contents of green-urban soils were greater than non-urban ones, which also proves the human influence on the metal content of soils.

The heavy metal concentration of soils was compared to the natural background values of soils defined by the Hungarian governmental regulation as well as to other urban soils from European cities that have roughly the same territory and population as Budapest (Table 4). In urban and green-urban soils, the mean concentration of Cu, Cr, Ni and Pb was larger than the natural background values of soils; furthermore, the concentrations of Cr and Pb were also greater compared with the mean of 11 European cities. Cu content of soils from urban sites is similar to values found in cities, such as Krakow and Stockholm, while Ni content was also similar to those of Stockholm. The soils of Budapest showed larger Fe levels and the lowest Mn and Zn levels of all cities.

Mobility of heavy metals is very dependent on the main soil properties (Alloway, 1995; Duruibe et al., 2007; Mónok & Füleky, 2017). According to several studies, heavy metals are less mobile at alkaline or moderately alkaline pH, which were measured mainly in urban soils (Biasioli et al., 2006; Mónok & Füleky, 2017; Zhao et al., 2007). The larger clay content of these soils may also contribute to metal immobilization (Alloway, 1995). SOC content can also modify the mobility of metal ions since it is binding them (Alloway, 1995; Duruibe et al., 2007; Yin et al., 2002). According to our results, this process probably occurring primarily in green-urban and non-urban soil.

### 3.3 Soil microbiological properties

According to Carreiro et al. (1999), microbial biomass can be 50% smaller in urban areas compared to non-urban ones. However, in our study there was no significant difference between different types of sites for the MPN of bacteria and fungi in soil (Table 5). Dehydrogenase activity (DHA) in urban soil samples was significantly less than in green-urban soil.

| Table 3: Statistical summary of the heavy metal concentrations in soils |
|-----------------------------------------------|
| **Co, mg kg⁻¹ | Cu, mg kg⁻¹ | Cr, mg kg⁻¹ | Fe, mg kg⁻¹ | Mn, mg kg⁻¹ | Ni, mg kg⁻¹ | Pb, mg kg⁻¹ | Zn, mg kg⁻¹ |
| Urban sites (n = 28) |
| Mean | 9.54 a | 56.24 a | 138.19 a | 464.38 a | 162.70 a | 28.20 a | 302.94 a | 47.11 a |
| Median | 10.25 | 54.74 | 155.90 | 464.55 | 160.72 | 28.71 | 274.61 | 41.41 |
| Max | 12.06 | 117.07 | 193.76 | 557.44 | 237.74 | 46.85 | 554.20 | 89.45 |
| Min | 3.84 | 27.28 | 45.30 | 359.27 | 124.48 | 14.40 | 204.36 | 11.77 |
| SE | 0.44 | 4.31 | 9.4 | 19.2 | 5.7 | 0.79 | 20.0 | 3.1 |
| Green-urban sites (n = 28) |
| Mean | 10.85 a | 32.63 b | 147.66 a | 459.80 ab | 174.75 a | 28.78 a | 217.93 b | 48.23 a |
| Median | 9.52 | 31.28 | 112.38 | 453.85 | 176.40 | 30.68 | 212.28 | 46.69 |
| Max | 14.50 | 52.51 | 263.18 | 529.87 | 239.30 | 42.91 | 299.59 | 81.58 |
| Min | 5.21 | 16.68 | 61.37 | 342.26 | 121.84 | 15.78 | 165.20 | 25.94 |
| SE | 0.74 | 0.78 | 14.7 | 18.2 | 3.2 | 1.42 | 6.8 | 2.4 |
| Non-urban sites (n = 16) |
| Mean | 9.80 a | 25.85 b | 25.44 b | 418.85 b | 176.18 a | 17.74 b | 170.50 b | 33.73 b |
| Median | 9.03 | 26.17 | 29.31 | 417.03 | 182.85 | 15.40 | 169.01 | 32.23 |
| Max | 14.57 | 43.08 | 53.75 | 544.31 | 228.10 | 30.18 | 264.65 | 61.54 |
| Min | 6.55 | 10.68 | 7.35 | 314.41 | 78.21 | 9.33 | 135.20 | 10.75 |
| SE | 0.65 | 1.43 | 4.2 | 13.2 | 8.2 | 1.59 | 9.9 | 2.0 |

Note: Different letters mean significant differences (< .05) for different sample sites by Tukey’s or Games–Howell’s test.
| City (country)          | Site type                  | Co, mg kg\(^{-1}\) | Cu, mg kg\(^{-1}\) | Cr, mg kg\(^{-1}\) | Fe, mg kg\(^{-1}\) | Mn, mg kg\(^{-1}\) | Ni, mg kg\(^{-1}\) | Pb, mg kg\(^{-1}\) | Zn, mg kg\(^{-1}\) | References                  |
|------------------------|----------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|--------------------------|
| Athens (Greece)        | Various sites              | 16                  | 48                  | 163                 | 240                 | 587                 | 111                 | 77                  | 122                 | Argyraki and Kelepertzis (2014) |
| Belgrade (Serbia)      | Urban and agricultural sites | n.m.               | 28.3               | 32.1                | n.m.                | n.m.                | 68                  | 55.5                | 118                 | Crnkovic et al. (2006)          |
| Berlin (Germany)       | Various sites              | n.m.               | 79.5               | 35.0                | n.m.                | n.m.                | 10.7                | 119                 | 243                 | Birke and Rauch (2000)          |
| Copenhagen (Denmark)   | Urban sites                | n.m.               | 58                  | n.m.                | 271                 | n.m.                | n.m.                | 233                 | n.m.                | Li et al. (2014)              |
| Glasgow (Great Britain)| Parks and allotments      | n.m.               | 140                 | 93                  | 353                 | n.m.                | 58                  | 971                 | 364                 | Hursthouse et al. (2004)         |
| Krakow (Poland)        | Parks                      | n.m.               | 55.5               | 16.3                | n.m.                | n.m.                | 10.5                | 120.2               | 176.7               | Gasiorek et al. (2017)           |
| Lisbon (Portugal)      | Parks and gardens          | n.m.               | 67.82              | 48.35               | 230                 | 294.96              | 41.84               | 114.12              | 156.84              | Costa et al. (2012)             |
| Napoli (Italy)         | Various sites              | 7.3                 | 94                  | 15.3                | 220                 | 683                 | 11.6                | 204                 | 223                 | Cicchella et al. (2008)          |
| Stockholm (Sweden)     | Various sites              | n.m.               | 55                  | 33                  | n.m.                | n.m.                | 25.8                | 79                  | 149                 | Linde et al. (2001)             |
| Torino (Italy)         | Parks and roadsides        | n.m.               | 90                  | 191                 | n.m.                | n.m.                | 209                 | 149                 | 183                 | Biasioli et al. (2006)           |
| Vienna (Austria)       | Urban sites                | 8.8                 | 18                  | 80                  | n.m.                | n.m.                | n.m.                | 65                  | 97                  | Simon et al. (2013)             |
| Means of the 11 European cities |                      | 10.70              | 66.74              | 70.71               | 262.80              | 521.65              | 59.60               | 198.80              | 183.25              |                           |
| Budapest (Hungary)     | Urban sites                | 9.54                | 56.24               | 138.19              | 464.38              | 162.70              | 28.20               | 302.94              | 47.11               | Present study                |
|                        | Green-urban sites          | 10.85               | 32.63               | 147.66              | 459.80              | 174.75              | 28.78               | 217.93              | 48.23               |                           |
|                        | Non-urban sites            | 9.80                | 25.85               | 25.44               | 418.85              | 176.18              | 17.74               | 170.50              | 33.73               |                           |
| Natural background value of soils in Hungary |                | 15                  | 30                  | 30                  | n.d.                | n.d.                | 25                  | 25                  | 100                 | Joint Decree No.10/2000           |

Abreviations: n.d., not defined; n.m., not measured.
and non-urban soils. Microscopic examination of bacteria showed that non-urban soils contain significantly larger numbers of bacteria than in urban and green-urban soil, which means that this method was more sensitive than the MPN method.

Previous studies suggested that soil heavy metal pollution decreases the microbial biomass (Aceves et al., 1999; Yang et al., 2006) and inhibits microbial enzyme activities (Kandeler et al., 1996; Wolińska & Stępniewska, 2012; Zhao & Li, 2013). It was also confirmed for different urban soils (Carreiro et al., 1999; Papa et al., 2010; Wang et al., 2011; Yang et al., 2006). According to Pearson’s correlation analysis (Table 6), Pb concentration of soils, which were fairly large in some urban and green-urban samples, negatively correlated with bacterial growth \( r = −.524; p < .001 \), DHA \( r = −.479; p = .002 \) and the number of bacterial cells \( r = −.392; p = .001 \). DHA had also a negative correlation with Cu \( r = −.476; p < .001 \) and Cr \( r = −.395; p = .004 \) content of soil, while positively correlated with Mn \( r = .510; p < .001 \) content. There was also a significant connection between Zn concentration and the number of bacterial cells \( r = −.470; p < .001 \) and

### Table 5 Statistical summary of the microbiological properties of soils

|                         | Bacterial growth \( \log_{10} \text{MPN g}^{-1} \) | Fungal growth \( \log_{10} \text{MPN g}^{-1} \) | DHA \( \text{TPF g}^{-1} \) | Number of bacterial cells \( \log_{10} \text{No cm}^{-3} \) |
|-------------------------|--------------------------------------------------|-------------------------------------------------|-----------------------------|--------------------------------------------------------|
| Urban sites \( n = 28 \) | Mean 2.16 a 0.33 a 0.77 a 8.89 a                   | Median 2.22 0.35 0.41 8.90                      | Max 2.38                    | Min 1.86 0.25 0.04 8.66                                  |
|                         | SE 0.02 0.004 0.14 0.02                           |                                                 |                             |                                                        |
| Green-urban sites \( n = 28 \) | Mean 2.24 a 0.35 a 1.45 b 8.98 a                   | Median 2.24 0.35 1.53 8.94                      | Max 2.45                    | Min 2.00 0.30 0.85 8.74                                  |
|                         | SE 0.01 0.003 0.11 0.03                           |                                                 |                             |                                                        |
| Non-urban sites \( n = 16 \) | Mean 2.26 a 0.36 a 1.54 b 9.20 b                   | Median 2.26 0.34 1.59 9.12                      | Max 2.46                    | Min 2.06 0.32 0.97 8.98                                  |
|                         | SE 0.02 0.004 0.18 0.06                           |                                                 |                             |                                                        |

*Note:* Different letters mean significant differences \( < .05 \) for different sample sites by Tukey’s or Games–Howell’s test.

### Table 6 Correlation between soil microbial properties and heavy metal concentrations in soils

|                  | Bacterial growth \( \log_{10} \text{MPN g}^{-1} \) | Fungal growth \( \log_{10} \text{MPN g}^{-1} \) | DHA \( \text{TPF g}^{-1} \) | Number of bacterial cells \( \log_{10} \text{No cm}^{-3} \) |
|------------------|--------------------------------------------------|-------------------------------------------------|-----------------------------|--------------------------------------------------------|
| Co, mg kg\(^{-1}\) | .057                                             | .158                                            | −.163                       | .198                                                   |
| Cu, mg kg\(^{-1}\) | −.257                                            | −.401*                                          | −.476*                      | −.278                                                  |
| Cr, mg kg\(^{-1}\) | −.182                                            | −.041                                           | −.395*                      | −.301                                                  |
| Fe, mg kg\(^{-1}\) | −.194                                            | .120                                            | −.306                       | −.241                                                  |
| Mn, mg kg\(^{-1}\) | .284                                             | .084                                            | .510*                       | .284                                                   |
| Ni, mg kg\(^{-1}\) | −.160                                            | −.175                                           | .090                        | −.077                                                  |
| Pb, mg kg\(^{-1}\) | −.524*                                           | −.300                                           | −.479*                      | −.392*                                                  |
| Zn, mg kg\(^{-1}\) | −.220                                            | −.297                                           | −.176                       | −.470*                                                  |

*Note:* Cells show the Pearson correlation coefficient \( r \).

* Means that coefficients are significant (two-tailed) \( p < .05 \).
between Cu concentration and fungal growth ($r = -0.401$; $p < 0.001$). These results are consistent with previous studies since negative correlations between these parameters indicate the inhibitory effects of heavy metals on soil microbial biomass and DHA.

The measured microbial parameters depend also on soil main properties besides heavy metal pollution (Papa et al., 2010). Therefore, Pearson’s correlation analysis was also performed between microbial characteristics and soil main properties (Table 7). SOC content was significantly correlated with all microbiological parameters ($r$ was between .373 and .628; $p$ ranged from .001 to .005). Organic substances in soils can enhance microbial activities since they form great source of energy for different microorganisms (Fontaine et al., 2003; Wolińska & Stępniewska, 2012). Thus, the smaller SOC content of urban samples partly explains the fewer bacterial cells and DHA. Artefact content of the soil was negatively correlated with all microbial parameters ($r$ was between $-0.629$ and $-0.484$; $p$ ranged from .001 to .022). It means that greater artefact content may cause reductions in the microbial biomass and DHA content of urban soils. This result would be expected as these parameters are extremely sensitive to human disturbance (Rai et al., 2018; Zhao & Li, 2013). N, P and K levels in soil can also influence microbial characteristics (Wolińska & Stepniewska, 2012). According to our results, the N content of soils was significantly correlated with DHA ($r = .374$; $p = .007$) and the number of bacterial cells ($r = .565$; $p = .007$). In relation to this, previous studies stated that lack of nutrients inhibits soil microbial biomass and activity (Geisseler & Scow, 2014; Wolińska & Stepniewska, 2012). Moreover, it is also notable that high pH and a greater CaCO₃ content in urban soils can negatively affect the form and availability of these nutrients for soil microorganisms (Li et al., 2013). Influences of pH on microbial biomass and activity are still inadequately understood since the literature results are quite ambiguous (Wolińska & Stepniewska, 2012). In our study, pH was significantly correlated with the number of bacterial cells; however, correlation coefficients were fairly low ($r = .387$ and .356).

### 4 | CONCLUSIONS

This study demonstrated that properties of grassland soils were strongly influenced by urban activities in Budapest. Soil artefact content, pH and CaCO₃ content were greater, while SOC and AL-extractable K contents in human-disturbed urban sites were less than in less-urbanized green-urban sites. In addition, soils in urban sites also showed significantly less DHA. It was also revealed that urban activities increased the heavy metal concentrations not only in urban, but also in green-urban soils. Cu, Cr, Ni and Pb contents of soils were larger than the natural background values, and Cr and Pb contents were greater than that of other European cities. Examination of the polluted sites should be continued.

According to our results, artefact content of soils was correlated with many chemical and microbiological properties; therefore, input of these materials probably plays
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DATA AVAILABILITY STATEMENT

The authors confirm that the data supporting the findings of this study are available within the article.

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