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A Complex Soil Ecological Approach in a Sustainable Urban Environment: Soil Properties and Soil Biological Quality

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Abstract: The main purpose of the present study was to monitor actual contamination levels and execute a comparative assessment of results in a mid-sized Hungarian city for two different years. The first citywide soil investigations were completed in 2011. In 2018, the most prominent properties (pH, $CaCO_3$, texture, and trace metals Cd, Co, Cu, Ni, Pb, and Zn) were reanalyzed and were supplemented with mesofauna on selected sites. The available trace metal elements of urban soils showed the following tendency in 2011: Zn > Cu > Pb > Cd > Cr = Ni = Co. In 2018, the previous order changed to Zn > Pb > Cu > Cr > Cd = Ni = Co. Cd and Pb enrichments were found, especially near the M7 motorway. The comparison between 2011 and 2018 revealed soil contamination was, on average, higher in 2011. Soil microarthropod communities were sampled and assessed using abundance data and diversity measurements. Soil biological quality was evaluated with the help of the Soil Biological Quality (QBS-ar) index. Acari and Collembola appeared to be the most abundant, ubiquitous taxa in the samples. Simultaneously, important groups like Symphyla, Protura, and Chilopoda were completely absent from the most polluted sites. For the most part, lower taxa richness, diversity, and QBS-ar index were observed with higher available Cu Zn, and Pb concentrations.

Keywords: soil properties; urban ecology; trace metal pollution; soil organisms; diversity

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Citation: Horváth, A.; Csáki, P.; Szita, R.; Kalicz, P.; Gribovszki, Z.; Bidló, A.; Bolodár-Varga, B.; Balázs, P.; Winkler, D. A Complex Soil Ecological Approach in a Sustainable Urban Environment: Soil Properties and Soil Biological Quality. *Minerals* **2021**, *11*, 704. https://doi.org/10.3390/min11070704

Academic Editors: Ana Romero-Freire and Hao Qiu

Received: 31 May 2021
Accepted: 27 June 2021
Published: 29 June 2021

1. Introduction

The impact of anthropogenic effects and environmental pollution creates an urgent need to investigate complex urban ecosystems. Soil, water, and sediment analysis complemented with biological indices (hydrobiological and mesofauna) can detect all prominent anthropogenic influences in the urban environment. Deficiencies within the national regulations of Hungary hinder the mitigation of adverse human effects. Moreover, complex investigations are often not well interpreted. Appropriate reference sources at the global level are also difficult to find.

Extensive evaluation of smaller aspects, like air quality monitoring with mosses [1] or detection of heavy metal content in dust [2], is available. Still, a knowledge gap exists regarding the long-term effects of these factors. The complexity of the current research requires a structured literature background for the parts of the study performed. The present study is part of a more complex analysis measuring urbanization effects on soil, water, sediment, mesofauna, and aquatic invertebrates.

Evaluations of the means, mobility, and interactions of heavy metal pollution in urban soils [3–7] have proven effective globally, both for soil development and ecosystem services [8]. Utilizing better knowledge of urban land use [9–11] or urban parks, schoolyards [12], or urban industry effects [13,14] not only improves the quality of life for urban residents but also aids in evaluating the impacts of different reclaimed land uses on topsoil properties. Soil development under different land use/cover is critical for restoring eco-environmental integrity and providing vital functions and services for city dwellers [15–17].

Urbanization is usually linked with changes in the soil environment, including habitat alteration, fragmentation and loss, and pollution, which also have strong negative effects on soil biota [18,19]. The diversified role of microarthropod communities in soil quality and health has been widely reported (e.g., [20,21]). Owing to their stability, relatively sedentary lifestyle, and sensitivity to soil property changes, specific taxa are often used as bioindicators of stressed environments [22,23]. The most frequently studied soil microarthropod groups in urban environments are Collembola and Acari (e.g., [24–27]); however, a more comprehensive evaluation of soil biological quality involving other microarthropod groups is also worth considering [19,28]. The novelty of our research is related to the fact that no complex ecological soil assessment (physicochemical and biological) has yet been carried out in urban environments in Hungary.

Despite the numerous urban soil studies in every continent that investigated the actual and increasing level of potential toxic elements (e.g., China [29], Poland [10], New York [30], Brazil [31], Angola [32]), we still do not have soil monitoring networks even at national levels. Particularly, many studies dealt with polycyclic aromatic hydrocarbon (PAH) and polychlorinated biphenyl (PCB) [33,34], or total element accumulation of urban parks [35], but less information has been published about available element contents [36]. Noticeable garden (fruit and vegetable) utilization is rather widespread in small and medium-sized cities. Gardens and urban parks or playgrounds could also bind airborne pollutants. Therefore, people may regularly come into contact with toxic elements accumulated by plants or soils of public parks or gardens. Thus, the determination of available trace metal contents is of particular importance. Due to the shortcomings mentioned above, our research has several goals, some of which are long term.

- The top priority of our research is to create a comprehensive database to complete the national system. Our national soil monitoring network does not examine the health conditions of human settlements.
- The long-term aim is to propose a modification of the existing soil limit system based on our results. Hungarian law only sets limits for total element content, e.g., for toxic trace metals. In our opinion, the limit values should also be completed with available toxic element limits to protect human health in urban areas.
- In addition, it is worth noting that in Hungary, the preparation of 4–6-year-long environmental programs for every settlement has been mandatory since 2006. Most of these programs are prepared with the involvement of a team of experts coordinated by the local government, but the prepared documents rely on unmeasured data. The lack of specific databases or municipal monitoring networks for cities is the reason for this. On the other hand, experts often rely on literature in their attempts to identify local problems affecting cities and offer suggestions from these literature-based findings. Most of these suggestions can only be called "symptom management" and do not attempt to uncover the "root problem". Therefore, experts can only make modest suggestions and lack the information needed to take definite steps.

Székesfehérvár, the city selected for the current paper, is the third in a closely linked citywide ecological status survey. It is worth noting that no complex citywide investigation had been completed in urbanized areas in Hungary before. The citywide urban soil investigation by Horváth et al. [37], recently conducted in Sopron and Szombathely, is a related research study. That study hypothesized that the Szombathely soils are more polluted than Sopron soils, but the investigation revealed Sopron soils to be more contaminated on average. The method employed in the current study differs from the one used for the two abovementioned cities in so far as the comparison of our results to the base year 2011 that was re-examined in 2018 also incorporates factors influenced by human activity. The city government has taken several municipal interventions aimed at sustainability. Therefore, the results of this current study reflect these positive effects of the interventions. We have already investigated these effects in water quality [38] and soil aspects as well. In 2018, the method was complemented by biological supporting measurements; we did not utilize these here.

Based on former experiences and conclusions, this study hypothesizes that pollution in Székesfehérvár has increased over the last seven years, with expected contamination increases in green areas. High pollution levels are also anticipated in the downtown area where heavy traffic is typical, especially near the M7 motorway. During the comparison of soil microarthropod groups, significant differences were expected in abundance between the less polluted suburban sites and the urbanized area sites. Based on our fact-finding, the population of Székesfehérvár started to increase from 1990. The area of the city also increased due to construction and occupation. General migration processes (from the east to the west) have occurred in the country since 2010. The continuous migration of the capital's population to the agglomeration is also an observable phenomenon. Both processes affected the city due to its favorable location. The city has operated nine industrial parks in the suburbs since the 2000s, where significant investments and developments (e.g., road network development) have been made to increase job opportunities. In addition, since the handover of the M7 motorway in 2008, commuter traffic and through traffic increased by 25% between 2010 and 2020. Based on previous expectations, the aims of the study were the following:

- to analyze the basic soil properties and available concentration of trace metals (Cd, Co, Cr, Cu, Ni, Pb, Zn) of the separate study years (2011 and 2018) and compare the results with suggested or legal limits;
- to compare and evaluate the results of 2011 to 2018 and estimate the changes in urban soils;
- to determine the degree of accumulation with enrichment factor (EF) calculations;
- to evaluate the quality and health of urban soil using the QBS approach;
- to clarify the directions of city development: Is Székesfehérvár still a livable city? Or do anthropogenic impacts have increasingly negative effects on soil and edaphon?

2. Materials and Methods

2.1. Study Area

Székesfehérvár, the city selected for this study, is located in Fejér County and has a population of 100,500 inhabitants. The city covers an area of 170.89 km^2 and is situated where Sárrét and South-Mezőföld merge. The elevations are between 103 and 222 m above sea level. On the eastern border of the city are the Velencei Mountains that consist of Carboniferous granite. During the rock formation process, the rocks of the mountain gradually sank deep into the east. The city is located in the northern part of the most extensive loess cover of the country; therefore, most of its territory is covered by thick loess. In the eastern part of the city, watercourses from the mountains to the north formed a significant alluvial cone on the Pannonian clayey sediments during the Pleistocene period. Due to the continuous subsidence, peat formation also appeared in some parts of this area in the Holocene [39]. The city's climate is warm and dry. The annual mean temperature is 10.2–10.4 °C, and annual precipitation is less than 540 mm. The most common winds are from the northwest, with an average speed of 2.5–3 m/s. The most important watercourse is the Gaja Brook, which runs through the city with many channels connecting to it. A natural saline lake (called "Sóstó") and some artificial lakes (a boating lake, fish ponds, and quarry lakes) and two large fish ponds can also be found in the city. The township is surrounded by degraded forests and grasslands or mostly utilized for agriculture. There are nine soil types in the investigated area, of which the productivity of Vertisols and Chernozems are the most favorable in the suburbs [40,41]. The natural conditions favor field crop cultivation [39,42]. Based on geological circumstances, loess-bedded forest soils (Luvisols) transformed into Technosols (Figure 1). These soils, mainly the topsoil layer formed by centuries-old human activities, are typical (IUSS Working Group WRB, 2014). The city is located on a busy travel route between the capital city Budapest and Lake Balaton, the biggest lake in Central Europe. The M7 motorway passes through the township from the south side; therefore, the city and its surroundings receive high traffic levels. During the analysis, an extremely high trace metal level was expected in the southeastern part of the city. In addition, the city's government has participated in many green programs and in recent years has received funding for urban greening, urban planning, soil remediation, road and park renovation, and dredging projects.

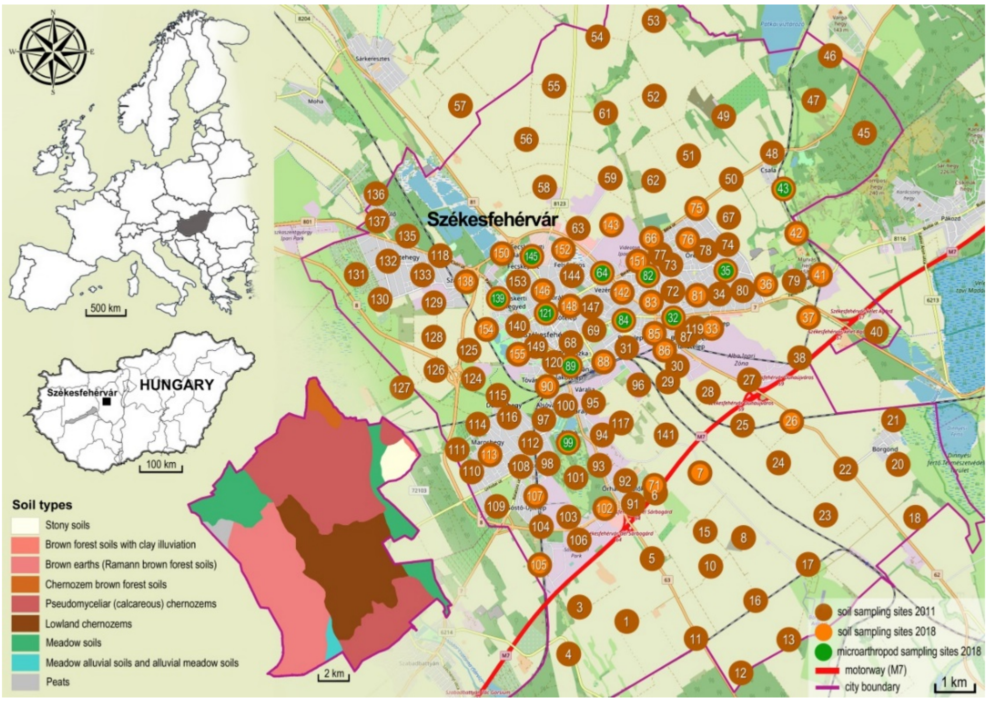

Figure 1. Distribution of sampling sites with soil type information of the study area (© OpenStreetMap contributors, soil map source: MTA TAKI 1991, https://www.openstreetmap.org, accessed on 29 June 2021).

2.2. Methods and Data Analysis

The effects of urbanization on the natural environment were the focus in the three western Hungarian cities (Sopron, Szombathely, and Székesfehérvár) selected as case study regions in 2010. The results of Sopron and Szombathely have already been published [37,43,44]. In addition, water quality analyses were carried out for the watercourses of Székesfehérvár [38]. The current paper will present the soil quality of the city. The chemical and physical characteristics of 144 soil surface samples were analyzed in Székesfehérvár and its surroundings in 2011. In 2018, 42 monitoring sites were revisited (Figure 1). During the research of pedological media, the following methods and measurements were implemented.

2.2.1. Soil Analysis

In 2011, 154 topsoil samples were collected from 0–10 and 10–20 cm depths; the sample number was eventually reduced to 144. In 2018, 42 topsoil samples were recollected from sites where some soil property or condition measured in 2011 warranted a re-examination. Altogether, 372 soil samples were analyzed during the research. Each test site was represented by three replications of randomly collected and then thoroughly mixed soil samples. The air-dried samples were sieved through a 2 mm mesh. The guidelines of the Hungarian Standards were used for sample preparation and methods of soil analysis (Table 1). These standards are in accordance with the methods of Van Reeuwijk [45]. Soil

pH_{H2O} (soil:solution ratio 1:2.5) was examined potentiometrically after 12 h of mixing to determine the mobility readiness of trace metals [46]. $CaCO_3$ content was measured with a Scheibler-type calcimeter [46]. Based on the standard [47], a sedimentation method (via the pipette method) was used for the determination of soil texture. A soil/water suspension was mixed in a sedimentation cylinder, and then sampled with a pipette to collect particles of a given size and calculate the ratio of clay (<0.002 mm), silt (0.002–0.02 mm), fine sand (0.02–0.2 mm), and coarse sand (0.2–2.0 mm). The skeletal percent (>2.0 mm) was separated from fine fractions with a sieve. Soil organic matter (SOM) content was determined following the FAO method [48,49]. As the 2011 results of the following measurement were negligible, they were not monitored in 2018. Kjeldahl total nitrogen, K_2O, P_2O_5, KCl extractable Ca-Mg, and EDTA/DTPA-extractable Fe, Mn, Cu, Zn analyses were not repeated, and their results will not be discussed in this study (Table 1).

Table 1. The summary of the pedological examinations.

Type of Measurements (Units)	Standard	2011/2018
Skeletal percent (%)	MSZ-08-0205/2:1978 [46]	+/+
pH (H_2O, KCl)—potentiometrically	MSZ-08-0205/2:1978 [46]	+/+
Total salinity (%)	MSZ-08-0205/2:1978 [46]	+/+
$CaCO_3$ (%)—Schleibler method	MSZ-08-0205/2:1978 [46]	+/+
Humus (%)—($K_2Cr_2O_7$ + cc. H_2SO_4)	MSZ-08-0452:1980 [49]	+/+
Texture (2–0.002 mm—%)	MSZ-08-0206:1978 [47]	+/+
Total nitrogen (%)	MSZ-EN-16169:2013 [50]	+/−
Potassium (K_2O, g/kg)—photometrically	MSZ-20135:1999 [51]	+/−
Phosphorus (P_2O_5, g/kg)—photometrically	MSZ-20135:1999 [51]	+/−
KCl-extractable calcium, magnesium (g/kg)—AAS	MSZ-20135:1999 [51]	+/−
EDTA/DTPA Fe, Mn, Cu, Zn (mg/kg)—AAS	MSZ-20135:1999 [51]	+/−
Available toxic element content (NH_4-acetate + EDTA)—ICP	MSZ 21470-50:2006 [52]	+/+
Mesofauna analysis (Soil Biological Quality—QBS)	Menta et al. [53]	−/+

+ analysis was carried out; − no analysis was carried out.

The available soil element fraction was measured in a 0.5 M NH4-acetate + 0.02 M EDTA extract [52,54]. The element concentrations were measured using the ICP-OES method (ICAP 6000 Series, Thermo Fisher Scientific, Waltham, MA, USA). Merck calibration standards were used for the element analyses, and the measurements were taken according to the manufacturer's instructions. Concentrations of Cd, Co, Cu, Ni, Pb, and Zn were determined with detection limits of 0.05, 0.14, 0.26, 0.28, 1.21, and 2.10 mg/kg, respectively. Each measurement session included the extract of a standard soil sample as a control. The calibration curves were determined after every twelfth sample. In order to ensure the required measuring accuracy, calibration was carried out in the international survey of the Forest Soil Co-ordination Center (FSCC)-INBO. The unit of measurement was mg/kg for Cd, Co, Cu, Ni, Pb, and Zn, with detection limits of 0.04, 0.12, 0.21, 0.28, 1.23, and 2.11 mg/kg, respectively. The results were evaluated based on the limit values of suggested thresholds by Kádár [55]. These limits are in accordance with contamination levels set by Hungarian law [56,57]. The field and laboratory results were processed using geospatial methods and were made compatible with the previous database (Microsoft Office vers. 2016).

2.2.2. Enrichment Factor Calculation

For pollution designation, total element fractions were also measured where mesofauna abundance was tested. The total trace metal amounts were analyzed (cc. 5 cm^3 HNO_3 + 2 cm^3 H_2O_2) in microwave Teflon bombs [54] using ICP-OES. Altogether, nine elements were measured (Al, Cd, Co, Cr, Cu, Pb, and Zn), but we focused on the most common urban pollutants that are prominent for mesofauna: Co, Cu, Ni, Pb, and Zn. The total fraction results were needed for enrichment factor (EF) calculations according to the concentration rate between the measured contamination of mesofauna samples and naturally occurring reference metal source concentrations (e.g., Al, Li, Ti, Zr [58]) in the crust and were modified by the following formula and categories [43].

$$EF\ sediment = \frac{\frac{X}{Al}\ sediment}{\frac{X}{Al}\ crust}$$

The applied reference element was Al, which is a common rock-forming element [59]. The crust averages for the investigated metals were studied by Taylor and McLennan [60]. There is no kind of pollution enrichment where EF is near to 1. Pollution enrichment (increasing anthropogenic impact) is expected in the case of EF rate >2 [61].

2.2.3. Soil Microarthropod Sampling and Identification

For the soil microarthropod surveys, three undisturbed soil samples of 100 cm^3 were taken from a depth of 10 cm using a cylindrical soil corer from each selected survey site. Soil microarthropods were extracted from the total of 33 soil samples into 70% ethanol within a two-week period using Berlese–Tullgren funnels. Microarthropod specimens were counted and identified at the major taxonomic group level using a stereomicroscope. Taxa diversity was determined for each plot using the Shannon formula [62], while evenness was calculated by Pielou's index [63]. Soil biological quality was assessed using the QBS-ar index [53,64], based on a classification of microarthropod groups present in the soil sample. Each biological form was assigned a value (ecological-morphological index (EMI)) ranging from 1 to 20 according to its adaptation level to the soil environment. The QBS-ar index summarizes the abovementioned EMI values derived from the actual sample [64]. In order to analyze the connection between soil parameters (pH, SOM, available trace metal content) and soil microarthropod communities, a canonical correspondence analysis (CCA) was performed using Canoco ver. 4.5 [65]. Taxa appeared in only one sample, and those that occurred at a low level (<5 individuals) were excluded due to possible uncertain relationships. A Monte Carlo permutation test with 1000 randomizations was performed to evaluate the significance of the canonical axes.

3. Results

3.1. Soil Data

The 144 sampling sites of 2011 were classified into land use categories by the most characteristic anthropogenic or environmental conditions according to the land registry. After the categorization, 40 residential, 37 agricultural, 19 traffic zone, 17 miscellaneous, 9 park, 7 forest, 7 creek bank and lake shore, 6 industrial zone, and 2 viticulture areas were separated (Table 2). In 2018, the selected 42 monitoring sites were reduced to 15 traffic zone sites, 9 park sites, 6 creek bank and lake shore sites, and 5 residential zone sites; the sampling network was completed with three forest sites, one industrial zone site, one agricultural site, and one grassland for reference. The distribution of land use categories is worth noting because only one sampling site was included in some categories, which greatly influenced the statistical analysis. However, the monitoring of these sampling sites was necessary as a control for confirming subsequent trace metal contents. Before trace metal evaluation, the general soil properties of the base year had to be introduced. Table 2 shows the distribution of watery soil pH, $CaCO_3$, texture, and SOM in 2011 in the study area by land use categories.

The pH of soil mostly determines soil characterization [66]. In Székesfehérvár, slightly alkaline soils were found in most cases. The average values were 7.3–8.1, and the lower results appeared in forested areas. In Table 2, the averages of $CaCO_3$ content clearly show the presence of calcareous sediments that appeared in categories with high anthropogenic activities. The maximum value (33% $CaCO_3$) was found in a traffic zone site in the city center. According to the particle size distribution, the clay (<0.002 mm) and silt fraction (0.002–0.02 mm) were less than sand (0.02–2.0 mm) in the urbanized areas. Nevertheless, the clay fraction did not exceed 22% and the samples were predominantly loamy. In a citywide context, there was a slight radial decrease in texture as the distance from the city center increased. In the case of SOM, the highest values were found in semi-natural categories. In summary, there were no notable differences in basic soil characteristics.

Table 2. Properties of the investigated soils of 2011: average values of particle size distribution, soil pH H_2O, $CaCO_3$ content, soil organic matter (SOM) in soils categorized by land use types and soil layer depth, n: number of samples.

Land Use Category	Sampling Depth	n	Texture (%)				pH (H_2O)	$CaCO_3$	SOM
		qty	Clay%	Silt%	Fine Sand%	Coarse sand%		%	%
Forested area	0–10 cm	7	13	9	37	41	7.3	12	5.88
	10–20 cm	7	11	11	35	43	7.4	12	4.33
Viticulture area	0–10 cm	2	14	16	34	36	7.9	8	2.97
	10–20 cm	2	13	12	36	39	7.9	8	3.19
Agricultural area	0–10 cm	37	22	21	47	10	8.0	13	4.26
	10–20 cm	37	22	20	47	11	8.1	15	3.70
Residential area	0–10 cm	40	13	13	44	30	7.9	25	3.99
	10–20 cm	40	13	14	44	29	7.9	17	3.94
Traffic zone	0–10 cm	19	15	13	46	26	7.9	15	3.67
	10–20 cm	19	14	13	46	27	8.0	19	3.08
Industrial area	0–10 cm	6	22	19	43	16	7.9	21	4.32
	10–20 cm	6	20	21	41	18	8.1	16	4.74
Creek and lake bank	0–10 cm	7	18	19	40	23	7.9	12	5.65
	10–20 cm	7	16	22	40	22	8.0	15	4.58
Park	0–10 cm	9	13	16	43	28	7.9	14	6.52
	10–20 cm	9	14	15	41	30	8.0	15	4.54
Miscellaneous	0–10 cm	17	16	20	46	18	7.8	21	3.36
	10–20 cm	17	18	18	44	20	7.9	19	2.92

Nevertheless, when the 2011 results were compared to the values of 2018 on the monitored sites, changes in soil properties became apparent. Over this period, the built environment of the city increased by 10%. The average pH_{H2O} of monitoring sites decreased to 7.7 from 7.9 in the 0–10 cm depth during the seven years. At the 10–20 cm depth, the average pH_{H2O} of monitoring sites decreased to 7.9 from 8.0. Figure 2a clearly shows that the number and value of outliers increased in 2018 in both layers that appeared in forested areas in the suburbs. The average $CaCO_3$ results also decreased by ~3% in 2018 in both layers (Figure 2b).

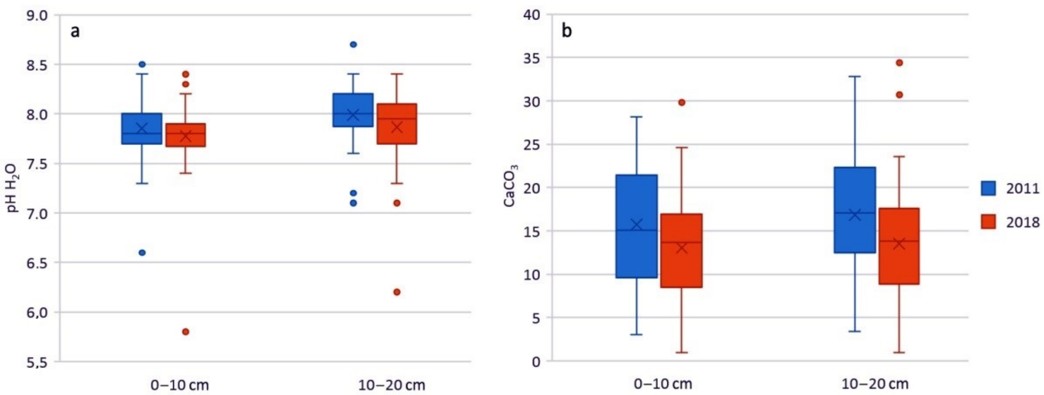

Figure 2. The distribution of pH_{H2O} (**a**) and $CaCO_3$ (**b**) content on the monitoring sites, 2011 vs. 2018.

In the case of texture, there were no significant changes between the averages. Soil texture is still loamy, but the averages hide the growth of sand fractions at each site (Figure 3). Changes in texture were observed in traffic zone sites (S88, S138, S151), in park sites (S121, S139), and creek/lake banks (S35, S154).

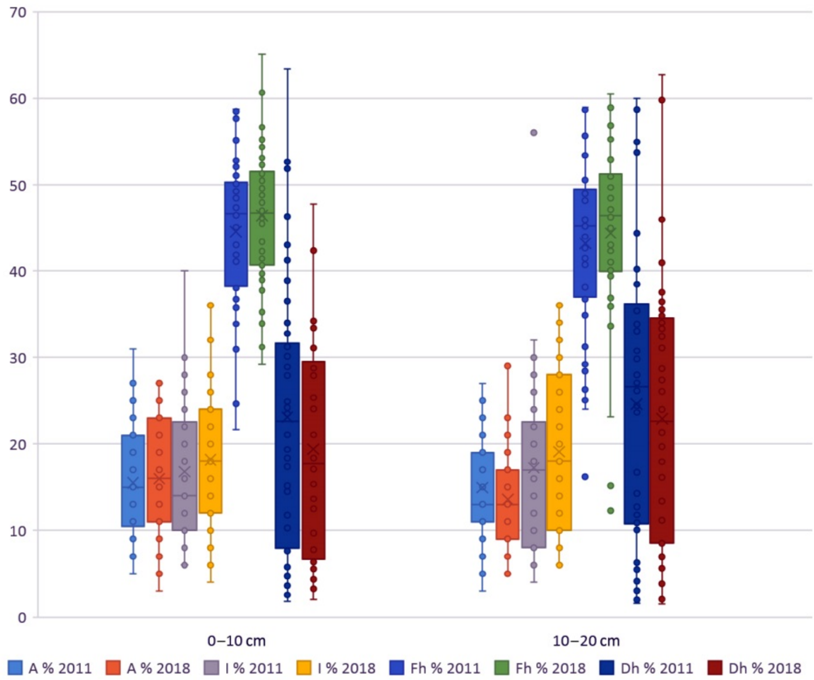

Figure 3. The distribution of soil fractions at 0–10 cm soil depth.

Table 3 summarizes the most important results of available trace metal analysis in both years where significant changes were detected. The available Co, Cr, and Ni values were lower than or close to the suggested natural background limits in both years. Extremes above the interventional pollution limits were observed at several sampling sites in 2011. At sampling site S86 (industrial area), the highest result was found in the case of Cu (408.4 mg Cu/kg) at a 0–10 cm depth. In addition, the highest Pb (97.5 mg Pb/kg) and Zn (247.5 mg Zn/kg) contents were found at this site as well. These extreme results were decreased in the 10–20 cm depth, but they still stand out. Sampling site S152 (miscellaneous) also showed high contents of Cd (2.5 mg Cd/kg), Cu (163.1 mg Cu/kg), Pb (38.2 mg Pb/kg), and Zn (63.3 mg Zn/kg) in the lower layer. In these mentioned sites, the pollution disappeared from samples in 2018. Considering the element occurrence, Zn exceeded the B, C1, and C2 limits most often in the base year. The available toxic elements of urban soils showed the following tendency in 2011: Zn > Cu > Pb > Cd > Cr = Ni = Co.

In 2018, samples taken alongside busy roads—especially near the M7 motorway—were contaminated with Zn and exceeded the "C1" limit (>40 mg Zn/kg) and "C2" limit (>80 mg Zn/kg). In the suburb, the amount of Pb decreased, especially in the southern part of the city. The measured elements showed the following quantitative order in 2018: Zn > Pb > Cu > Cr > Cd = Ni = Co (Figure 4).

The most significant negative changes were detected in samples of traffic zones (S102, S107, S138), which are near the M7 motorway. Furthermore, the trace metal content of a park (S90) and a creek/lake bank (S99) sample increased. In summary, the results showed that soils were more polluted in the base year.

3.2. Enrichment Factor Calculation

To complete the previous determinations, the collected samples on mesofauna sampling sites were evaluated and normalized with Al content. Enrichment factors were calculated and assessed according to the terms in the table below (Table 4).

Table 3. Available trace metal concentration of soil samples on selected sites classified by pollution limits.

2011							Site Nr.	2018							2011 vs. 2018							Land Use Category
Cd	**Co**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**		**Cd**	**Co**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**	**Cd**	**Co**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**	
0.23	0.77	0.01	3.92	1.50	13.79	29.41	S7	0.24	2.30	0.20	6.31	3.94	18.62	12.36	0.01	1.53	0.20	2.39	2.43	4.83	−17.05	traffic zone
0.53	1.15	0.47	10.99	2.71	21.95	44.05		0.20	2.18	0.17	6.08	3.82	13.64	11.49	−0.32	1.02	−0.30	−4.90	1.11	−8.31	−33.01	
0.28	1.30	0.03	14.92	1.51	66.34	53.81	S32	0.18	0.47	0.32	17.85	0.90	20.90	54.66	−0.09	−0.83	0.32	2.93	−0.60	−45.44	0.85	traffic zone
0.23	1.31	0.06	13.40	1.42	70.51	23.65		0.10	0.29	0.41	8.30	0.84	14.64	22.31	−0.13	−1.02	0.41	−5.09	−0.57	−55.87	−1.34	
0.19	1.08	0.21	8.09	1.72	9.10	42.13	S81	0.24	1.86	0.11	6.71	3.53	10.97	12.22	0.043	0.78	−0.09	−1.38	1.81	1.86	−29.91	residential area
0.17	1.06	0.20	7.21	1.78	7.68	31.82		0.17	1.50	0.10	5.02	2.72	9.32	8.95	0.01	0.44	−0.09	−2.19	0.93	1.63	−22.86	
0.18	0.63	0.21	7.14	0.86	17.06	24.95	S85	0.14	0.77	0.14	7.42	0.99	11.12	22.71	−0.04	0.13	−0.06	0.25	0.13	−5.94	−2.24	traffic zone
0.20	0.69	0.24	5.90	0.87	16.29	23.55		0.12	0.71	0.14	4.88	1.24	13.52	13.34	−0.07	0.01	−0.09	−1.01	0.36	−2.77	−10.21	
2.36	1.20	1.25	408.4	2.51	97.45	247.5	S86	0.31	1.10	0.30	9.54	1.55	47.95	25.96	−2.05	−0.09	−0.94	−398.85	−0.95	−49.5	−221.54	industrial area
1.45	1.03	0.95	180.9	1.36	73.45	93.86		0.25	0.89	0.33	6.98	1.34	29.49	14.81	−1.20	−0.13	−0.61	−173.91	−0.02	−43.96	−79.05	
0.36	0.43	0.56	13.14	1.08	28.71	58.09	S90	0.58	0.66	0.63	27.55	1.79	23.80	65.54	0.22	0.22	0.07	14.41	0.71	25.09	7.45	park
0.41	0.39	0.58	11.78	0.94	30.74	59.69		0.33	0.42	0.39	22.59	1.16	35.24	42.17	−0.07	0.03	−0.18	10.81	0.22	4.51	−17.52	
0.17	0.33	0.20	1.88	0.49	2.96	8.96	S99	0.62	0.43	0.43	11.52	0.99	25.92	35.93	0.44	0.09	0.22	9.63	0.50	22.95	26.96	creek and lake bank
0.11	0.29	0.26	1.93	0.50	2.76	4.91		0.56	0.32	0.41	11.62	0.97	25.02	34.66	0.45	0.02	0.15	9.68	0.46	22.26	29.74	
0.11	0.94	0.10	3.01	1.71	3.63	4.98	S102	0.15	0.97	0.21	17.44	1.90	5.09	52.98	0.04	0.03	0.10	14.42	0.18	1.46	47.99	traffic zone
0.10	0.87	0.10	2.61	1.68	3.18	2.60		0.16	1.11	0.14	10.47	2.18	4.83	28.15	0.05	0.24	0.04	7.85	0.49	1.65	25.54	
0.35	0.49	0.46	8.99	0.95	16.88	36.47	S107	0.52	0.40	0.93	15.54	0.74	43.02	52.43	0.17	−0.08	0.47	6.54	−0.21	26.14	15.96	traffic zone
0.46	0.36	0.80	13.11	0.88	27.37	44.28		0.56	0.45	1.27	21.52	0.89	39.89	69.18	0.10	0.09	0.46	8.41	0.01	12.52	24.90	
0.15	0.34	0.28	2.93	0.44	5.27	29.24	S138	0.28	0.75	0.30	5.18	0.63	10.06	80.40	0.13	0.41	0.01	2.25	0.18	4.78	51.16	traffic zone
0.24	0.29	0.47	2.91	0.43	5.47	24.40		0.31	0.54	0.32	4.33	0.55	9.87	98.67	0.07	0.25	−0.15	1.41	0.12	4.40	73.77	
0.27	0.42	0.18	6.28	1.14	13.65	31.52	S139	0.36	0.59	0.23	6.40	1.46	22.75	26.38	0.09	0.16	0.04	0.11	0.31	9.10	−5.14	park
0.44	0.38	0.22	7.94	1.15	16.24	28.33		0.44	0.47	0.28	7.72	1.39	27.34	26.22	−0.01	0.09	0.08	−0.22	0.23	11.10	−2.11	
2.51	0.62	0.53	13.03	1.14	9.85	22.32	S150	0.23	0.18	0.33	6.39	0.43	12.77	10.93	−2.27	−0.44	−0.20	−6.63	−0.70	2.92	−11.39	forested area
0.33	0.40	0.28	80.36	0.93	23.35	30.93		0.25	0.16	0.33	6.69	0.41	13.38	11.41	−0.07	−0.24	0.05	−73.66	−0.52	−9.97	−19.52	
2.19	1.46	1.81	120.6	2.59	43708	53.40	S152	0.17	0.54	1.02	3.83	1.02	8.51	8.88	−2.02	−0.92	−0.79	−116.76	−1.57	−22.56	−44.51	miscella neous
2.52	0.90	1.19	163.10	2.12	38.15	63.32		0.25	0.48	0.36	5.75	1.19	11.73	17.02	−2.27	−0.42	−0.82	−157.34	−0.93	−26.42	−46.3	
0.11	0.32	0.25	2.77	0.55	3.10	4.01	S155	0.50	0.34	0.47	5.26	0.49	8.05	16.39	0.39	0.02	0.22	2.48	−0.05	4.94	12.37	residential area
0.11	0.37	0.30	3.27	0.73	2.56	2.32		0.58	0.36	0.52	5.65	0.50	10.43	16.54	0.46	−0.01	0.22	2.38	−0.23	7.86	14.21	
0–0.5	0–5	0–0.5	0–10	0–10	0–10	0–5	<A	0–0.5	0–5	0–0.5	0–10	0–10	0–10	0–5								
0.5–1	5–10	0.5–3	10–40	10–20	10–25	5–20	A < X < B	0.5–1	5–10	0.5–3	10–40	10–20	10–25	5–20								
1–2	10–20	3–6	40–90	20–60	25–70	20–40	B < X < C1	1–2	10–20	3–6	40–90	20–60	25–70	20–40				increase				
	20–30	6–18	90–140	60–90	70–150	40–80	C1 < X < C2		20–30	6–18	90–140	60–90	70–150	40–80								
	30–40	18–36	140–190	90–120	150–300	80–160	C2 < X < C3		30–40	18–36	140–190	90–120	150–300	80–160				decrease				
	40<	36<	190<		300<	160<	C3 < X		40<		190<	120<	300<	160<								

Notes: “A”: background concentration, “B”: pollution limit, “C1”: first interventional limit, “C2”: second interventional limit, “C3”: third interventional limit based on the suggested limits for the method of Lakanen-Erviö [54] by Kádár [55] for Hungarian soils. All concentrations are indicated in mg/kg.

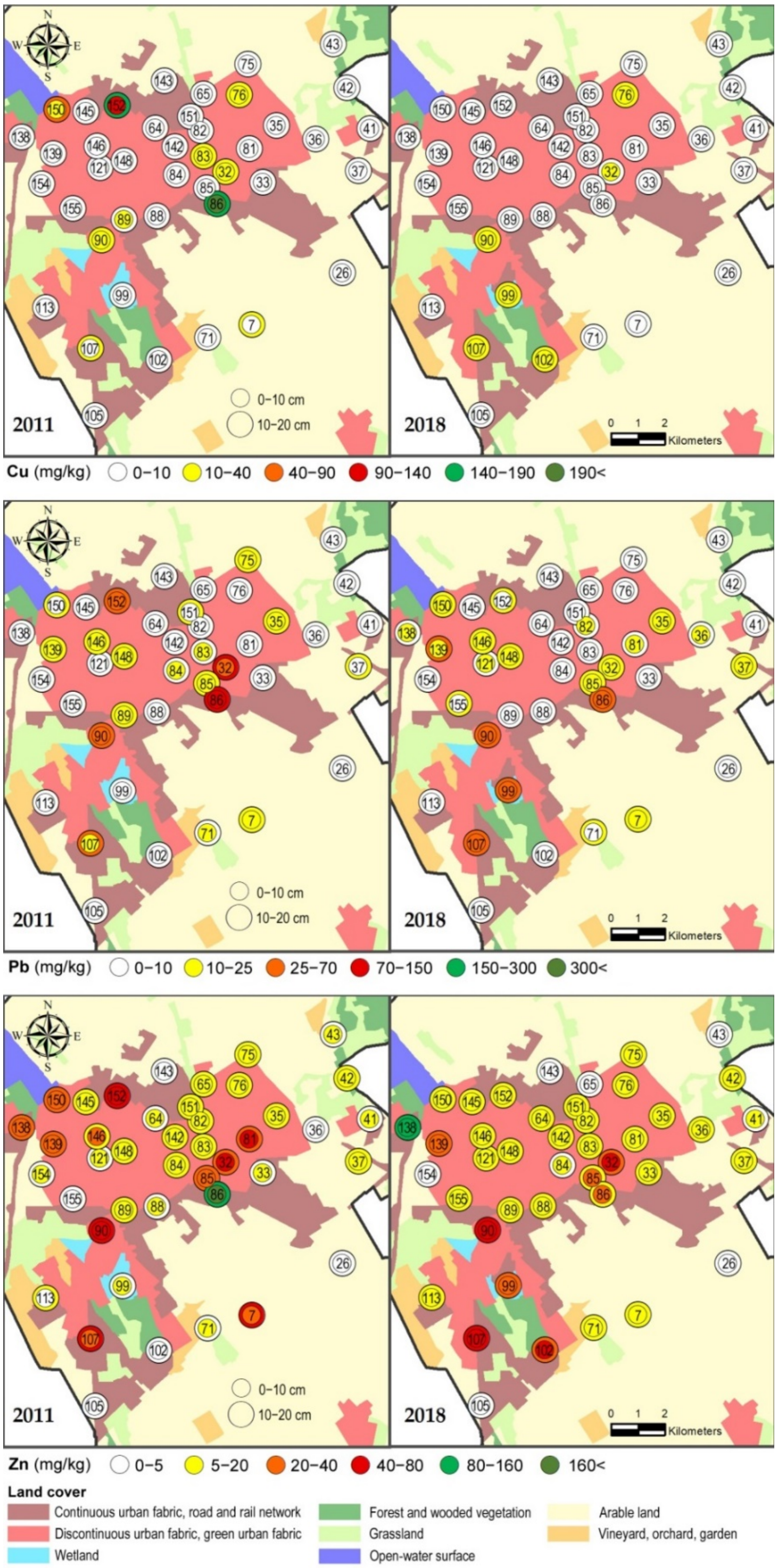

Figure 4. Comparison of the spatial distribution of available Cu, Pb, and Zn results in selected sites in 2011 vs. 2018 (EEA 2012, EEA 2018).

Table 4. Toxic element enrichment of soil samples on selected sites classified by pollution limits.

Site Nr.	Available							Total							Enrichment Factor						
	Cd	**Co**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**	**Cd**	**Co**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**	**Cd**	**Co**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
S32	0.18	0.47	0.32	17.85	0.90	20.90	54.66	0.25	4.25	25.10	42.22	12.95	33.65	119.81	2	0	0	1	0	4	2
S35	0.44	0.91	0.20	3.46	1.01	17.56	11.79	0.49	7.66	28.65	15.58	14.05	44.25	102.24	2	0	0	0	0	2	1
S43	0.13	1.45	0.36	4.55	1.85	4.84	2.73	0.15	6.22	28.94	15.65	17.33	9.87	41.30	1	0	0	0	0	1	0
S64	0.22	1.12	0.31	6.42	2.05	6.56	11.64	0.28	7.92	38.18	24.70	21.36	15.44	62.82	1	0	0	0	0	1	1
S82	0.27	1.11	0.26	8.17	2.16	11.31	9.70	0.33	8.16	35.79	27.99	22.13	21.32	68.03	1	0	0	0	0	1	1
S84	0.16	0.91	0.53	3.48	0.93	8.02	6.17	0.19	5.70	25.15	15.64	14.35	15.12	45.25	1	0	0	0	0	1	1
S89	0.18	0.34	0.32	6.42	0.36	9.15	12.67	0.18	3.86	18.13	23.79	9.94	17.47	47.55	1	0	0	1	0	2	1
S99	0.62	0.43	0.43	11.52	0.99	25.92	35.93	0.67	3.99	19.06	27.97	12.35	33.49	94.44	4	0	0	1	0	3	2
S121	0.13	0.56	0.23	5.63	1.06	12.37	7.97	0.16	5.55	25.19	19.45	15.27	20.89	47.28	1	0	0	0	0	2	1
S139	0.36	0.59	0.23	6.40	1.46	22.75	26.38	0.57	4.67	22.93	19.57	11.97	33.21	81.87	3	0	0	0	0	3	1
S145	0.25	1.08	0.42	4.13	1.49	9.91	9.3	0.29	7.21	34.54	22.10	22.84	16.23	64.41	1	0	0	0	0	1	1
A>	0–0.5	0–5	0–0.5	0–10	0–10	0–10	0–5	0–0.5	0–15	0–30	0–30	0–25	0–25	0–100	≤1	no enrichment					
A< X < B	0.5–1	5–10	0.5–3	10–40	10–20	10–25	5–20	0.5–1	15–30	30–75	30–75	25–40	25–100	100–200	≤3	minor enrichment					
B < X < C1	1–2	10–20	3–6	40–90	20–60	25–70	20–40	1–2	30–100	75–150	75–200	40–150	100–150	200–500	3–5	moderate enrichment					
C1 < X < C2		20–30	6–18	90–140	60–90	70–150	40–80	2–5	100–200	150–400	200–300	150–200	150–500	500–1000	5–10	moderate enrichment					
C2 < X < C3		30–40	18–36	140–190	90–120	150–300	80–160	5–10	200–300	400–800	300–400	200–250	500–600	1000–2000	10–25	severe enrichment					
>C3		40<	36<	190<	120<	300<	160<	10<	300<	800<	400<	250<	600<	2000<	25–50	very severe enrichment					

Note: According to the risk substance concentration levels for pseudo-total fraction set forth in legislation [56,57], the term "A" (background concentration) indicates the typical particular substance reflected under natural conditions in soil. The term "B" (background concentration) represents a risk substance, with due regard, in the case of groundwater, to the requirements of drinking quality and the aquatic ecosystem and, in the case of the geological medium, to the full range of soil functions and the sensitivity of groundwater to pollution. The term "C" refers to the interventional pollution limit level.

Table 5. EMI scores and soil microarthropod abundance (ind./m^2), number of taxa, Shannon diversity, equitability, and QBS-ar index values (mean ± SE) of the soil samples collected from selected sites.

Microarthropod Taxa (EMI Scores)	Site Nr.										
	S32	**S35**	**S43**	**S64**	**S82**	**S84**	**S89**	**S99**	**S121**	**S139**	**S145**
Acari (20)	4415 (1103)	9122 (2450)	9392 (3212)	7130 (1460)	5141 (1419)	8500 (2507)	5519 (1219)	6644 (1600)	5563 (1844)	6781 (2260)	10,133 (2970)
Araneae (1–5)	33 (19)	67 (51)	133 (69)	0 (0)	0 (0)	189 (89)	56 (40)	0 (0)	0 (0)	0 (0)	78 (48)
Chilopoda (10)	0 (0)	89 (73)	56 (40)	0 (0)	22 (11)	0 (0)	33 (33)	44 (29)	0 (0)	0 (0)	89 (73)
Coleoptera (1–20)	33 (19)	56 (40)	78 (29)	56 (40)	0 (0)	0 (0)	0 (0)	56 (40)	0 (0)	0 (0)	67 (40)
Collembola (1–20)	822 (323)	4085 (946)	4481 (1084)	3200 (869)	1626 (454)	2270 (679)	3019 (940)	1578 (551)	2578 (1039)	3544 (1126)	4526 (930)
Diplopoda (10–20)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	67 (33)	0 (0)	0 (0)	78 (48)
Diplura (20)	0 (0)	222 (142)	256 (78)	78 (48)	56 (40)	67 (38)	0 (0)	156 (91)	0 (0)	89 (59)	44 (29)
Hemiptera (1–10)	122 (68)	0 (0)	0 (0)	89 (72)	0 (0)	133 (58)	0 (0)	89 (40)	0 (0)	0 (0)	111 (48)
Hymenoptera (1–5)	644 (367)	0 (0)	111 (68)	522 (185)	944 (244)	722 (193)	211 (87)	0 (0)	467 (168)	800 (150)	1089 (330)
Isopoda (10)	0 (0)	56 (40)	44 (29)	0 (0)	11 (11)	44 (29)	0 (0)	0 (0)	0 (0)	0 (0)	56 (40)
Pauropoda (20)	0 (0)	0 (0)	89 (29)	67 (19)	0 (0)	89 (56)	78 (56)	0 (0)	0 (0)	0 (0)	56 (22)
Protura (20)	0 (0)	0 (0)	56 (11)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	122 (59)
Pseudoscorpionida (20)	0 (0)	56 (29)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	144 (87)
Psocoptera (1)	0 (0)	0 (0)	0 (0)	33 (33)	0 (0)	111 (62)	0 (0)	0 (0)	67 (38)	0 (0)	0 (0)
Symphyla (10)	0 (0)	56 (40)	189 (172)	0 (0)	78 (29)	0 (0)	78 (48)	0 (0)	56 (29)	0 (0)	89 (48)
Thysanoptera (1)	0 (0)	22 (11)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	89 (89)	0 (0)
Coleoptera larvae (10)	33 (33)	178 (40)	111 (44)	0 (0)	0 (0)	67 (67)	0 (0)	122 (59)	0 (0)	111 (44)	133 (51)
Diptera larvae (10)	167 (107)	56 (22)	356 (59)	244 (91)	89 (29)	0 (0)	56 (40)	0 (0)	111 (95)	144 (80)	22 (22)
Hymenoptera larvae (10)	0 (0)	56 (56)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Taxa richness	6.00 (1.15)	10.0 (0.58)	11.67 (0.88)	7.33 (0.67)	6.67 (0.67)	8.67 (0.33)	6.00 (0.58)	7.00 (0.58)	5.33 (0.88)	6.00 (0.58)	13.33 (0.33)
Shannon index	0.64 (0.21)	0.74 (0.11)	0.80 (0.05)	0.76 (0.09)	0.78 (0.04)	0.76 (0.13)	0.73 (0.07)	0.59 (0.15)	0.68 (0.08)	0.82 (0.05)	0.86 (0.10)
Pielou's index	0.51 (0.12)	0.40 (0.05)	0.43 (0.02)	0.49 (0.04)	0.53 (0.03)	0.47 (0.08)	0.49 (0.05)	0.38 (0.08)	0.52 (0.06)	0.57 (0.04)	0.45 (0.05)
QBS-ar index	61.0 (6.4)	125.7 (7.5)	153.3 (7.3)	92.7 (8.3)	88.3 (8.8)	95.3 (6.7)	77.0 (4.4)	94.3 (9.3)	59.0 (3.0)	78.7 (6.8)	162.7 (10.9)

During the trace metal investigations, site S32 (traffic zone) showed moderate enrichment of Pb and minor enrichment of Cd, Cu, and Zn. Moderate Cd and Pb enrichment were also typical for site S99 (creek and lake bank) and S139 (park). At these sites, extremely high results were detected during the soil monitoring as well. In detail, Cd, Pb, and Zn showed minor enrichment at almost every site. Cr, Co, and Ni enrichments were negligible. The rank order of mobility for these elements was Pb > Cd > Zn > Cu = Cr = Ni = Co.

3.3. Soil Microarthropods

A total of 11,014 microarthropod specimens belonging to 19 different groups were extracted from soil samples (Table 5). Cumulative taxa richness per site ranged from a minimum of six (site S121) to a maximum of 16 at site S145, whereas total microarthropod abundance ranged from a minimum of 5222 ind. m^{-2} at site S82 to a maximum of 21,789 ind. m^{-2} at site S145. Acari and Collembola appeared to be the two most abundant taxa, representing 68.6% and 27.8% of the extracted microarthropods, respectively. Percentages of the other groups were markedly lower, and with the exception of Hymenoptera (Formicidae), none of them reached 1% of the total arthropod number. Among the microarthropod taxa, Acari and Collembola were ubiquitous; moreover, the frequency of Diplura and Hymenoptera was considerably high.

The Shannon index indicated the highest diversity at site S145 and the lowest at site S99. Pielou's index suggested the highest evenness at site S139 and the lowest at site S99. The values of the QBS-ar index varied within a wide range, from 51 to 176; the lowest and highest were associated with sites S32 and S145, respectively. Examining the relationship between the indices calculated above and the soil physicochemical properties, only Shannon diversity showed a significant correlation with Cu and Zn content ($p < 0.05$; $r = -0.66$ and $r = -0.62$, respectively).

The CCA analysis explored a more detailed relationship between soil fauna and soil environmental factors (Figure 5). The first two axes together explained 70.7% (46.3% and 24.4%, respectively) of the total variance in microarthropod taxa distribution. As the Monte Carlo permutation test proved, eigenvalues of the first two canonical axes were significant ($p < 0.01$ and $p < 0.05$, respectively). The first axis of this data set mainly represents the trace metals Pb, Cu, and Zn, and, furthermore, soil pH and organic matter content (SOM), whereas the second axis is mainly governed by metals Cd, Co, and Ni. Along axis 1, the dispersion of microarthropod taxa distinguished the more polluted plots and those less affected by trace metal accumulation. Chilopoda, Diplura, Pauropoda, and Symphyla appeared to be the most sensitive groups, projected on the negative side of axis 1. The groups Pseudoscorpionida, Protura, Isopoda, and Collembola were more prevalent in less polluted or moderately polluted soils. At the same time, Acari, Psocoptera, Hemiptera, and Hymenoptera (Formicidae) were also present in considerable numbers in soils markedly polluted by Pb, Zn, or Cu.

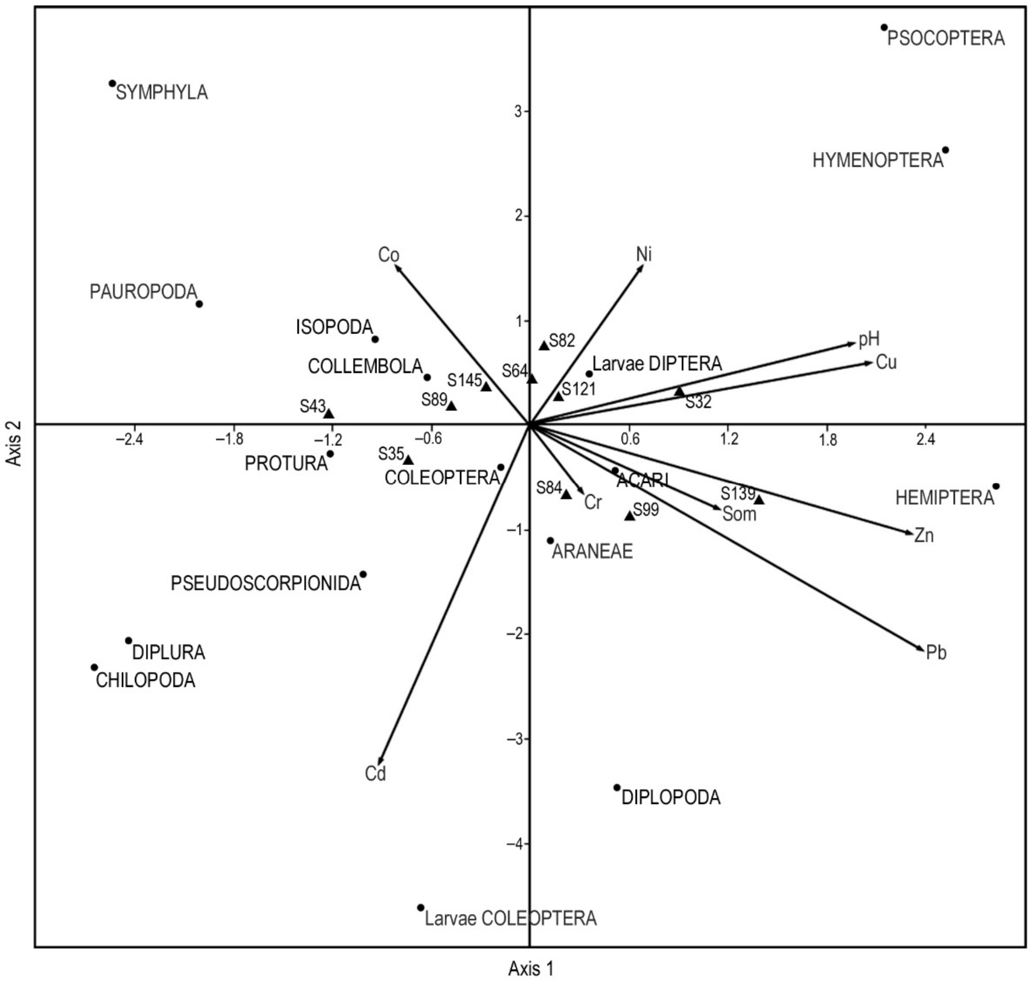

Figure 5. Ordination biplot of canonical correspondence analysis (CCA) of soil physical and chemical properties and soil microarthropod taxa (dots). Triangles represent the sampling sites (for site numbers, see Figure 1).

4. Discussion

4.1. Evaluation of Soil Analysis

Despite the heterogeneity of the city, the comparison of soil properties was difficult. However, similarities and frequencies can be detected by performing measurements. The impact of geological processes can be demonstrated with bedrock, which is related to the spatiality of urbanized areas. In the case of Székesfehérvár, the acidic parent material—granite—of the Velence Mountains affected the peripheral areas of the northeastern part. However, soils of the urbanized areas were influenced not only by the mountains' acidic forest soils but also by sediments and deposits as a result of geological soil formation and transformed by anthropogenic activities. Therefore, soil pH was generally slightly alkaline in both years; hence, high trace metal concentrations were not characteristic. Stream deposits cover the suburban and urban sites located in the Mezőföld, the sediment of which has a watery pH that is slightly alkaline (pH_{H2O} 7.9–8.1). Thus, the results of the settlement were similar to values found in the city of Sopron at about pH 8.0 [37]. The arable lands of Székesfehérvár are still under cultivation throughout the suburbs of the city. The use of fertilizers or pesticides is typical [67,68]. Based on pH results of 2011 versus 2018, a small decreasing tendency was detected. The decrease in average pH_{H2O} values means that a soil acidification process was already apparent in the area. However, the earlier average of 0.42 increased to 0.48. A value of 0.8 was barely measured over a span of seven years but, currently, a value of 0.9 shows an increase in susceptibility to soil acidification. Alkalinity of soil impedes the mobility of anthropogenic contaminants in urban soils because pollutants tend to bind within this range; therefore, they cannot leach into lower soil layers or water bases. However, if this acidification tendency continues, pollutants will become more mobile.

Consequently, $CaCO_3$ content was high in samples due to geological conditions. Despite the significant increase in the skeleton percentage—debris, artefacts, and construction waste—lime content was lower in 2018 than it was in 2011. The city was a coronation and burial place for Hungarian kings in the Middle Ages. The building materials originate from the nearby mountains (e.g., limestone, dolomite, granite). However, the highest concentrations of $CaCO_3$ were found in creek and lake banks. The reason for this is Gaja Brook, which flows through the city area. The catchment area of the Gaja is located in the karstic, limestone–dolomite–marlic Bakony Mountains. The brook drains off the excess water until reaching Székesfehérvár. Soil texture in Székesfehérvár is quite varied, which may be due to the different types of deposits and the characteristics of the Mezőföld. Between the soil samples, loam, clay loam, and sandy loam were typical in both layers in both years. The soils around the city are suitable for agricultural cultivation because of favorable climatic conditions in the area. The presence of sand is attributed to to the origin of the soils, while the rivers and streams that were active in the lower and middle Pleistocene deposited Pannonian clay sediments in the area [42], and loess was deposited as well. The other reason is that sand is a popular filler and is often mixed into the soil in the course of construction and renovation projects. These characteristics were typical in the city of Szombathely as well [37].

The increasing environmental risk of a particular toxin is demonstrated by amounts exceeding pollution limits. The available Co, Cr, and Ni contents were negligible in the investigated topsoil layer. Based on Li et al. [69], plants can accumulate small amounts of Co, Co, or Ni that do not bind to humus [70]; therefore, these two mobile elements appear in deeper layers near the parent material. The city is located in Hungary's most significant geochemical region where the covered sediment of streams made excellent arable lands, and most of the elements can enter into the soil with fertilizers and pesticides, Cd^{2+}, Cu^{2+}, Pb^{2+}) [71]. According to previous studies [72], Cu and Cd deposition on the surface of the soil was mainly due to vehicle corrosion, tire wear, or air pollution. Cd accumulation was found near the M7 motorway, and extremes also appeared in the southern part of the city, where busy road traffic is typical. According to Meuser [73], heavy metal concentration decreases with distance from roads and with soil depth. It is estimated that about 10% of the lead released is deposited within 100 m [74]. In Székesfehérvár, Cu values did not exceed the pollution limit (40 mg Cu/kg), but extreme limit excesses (e.g., 408 mg Cu/kg) were more characteristic in 2011. The extremely high results were detected in an industrial zone and in a grassland site in the suburb. The mentioned areas are located next to viticulture areas and arable lands where pesticide use is already characteristic.

Pb is only slightly mobile in alkaline soils, and it binds to clay mineral or humic substances. In the acidic soils of the suburban areas, the mobility of Pb increased similarly to Cd, where low contamination already carried risks for the environment. Previously, the greatest source of Pb was fuel, but the use of leaded fuel was banned in the 1990s. In addition, lead-rich paints were used previously to treat buildings externally, with the aging and dusting of soils in the nearby soils, which resulted in several studies in the 1980s (e.g., [75]). Many houses contain lead-rich paint in Hungary, even today. The city experienced an expansion period in 2011, but the expected population and economic growth experienced then has stagnated today. In addition to migration into cities, labor migration has emerged as a new factor in recent years. Samples taken alongside busy roads, especially in the city center, were contaminated with Pb due to the continuous traffic. Only a small part of the Zn compounds originated from traffic and transport. Zn and its compounds are a constant accompaniment to anthropogenic effects because the element exists in many household, industrial, and agricultural materials [73].

The comparison of results is difficult because other authors have analyzed total element content in general. Therefore, the results of Székesfehérvár were compared to trace metal contents of Sopron and Szombathely, which were measured by the authors. Székesfehérvár is clearly more contaminated with Cd (2011: 0.33 mg Cd/kg on average, 2018: 0.26 mg Cd/kg on average), Co (2011: 0.76 mg Co/kg on average, 2018: 0.87 mg Co/kg on average), Cr (2011: 0.31 mg Cr/kg on average, 2018: 0.34 mg Cr/kg on average), Cu 2011: 17.00 mg Cu/kg on average, 2018: 6.38 mg Cu/kg on average), Ni (2011: 1.31 mg Ni/kg on average, 2018: 1.42 mg Ni/kg on average), Pb (2011: 13.01 mg Pb/kg on average, 2018: 11.98 mg Pb/kg on average), and Zn (2011: 19.07 mg Zn/kg on average, 2018: 15.70 mg Zn/kg on average) by mean values. Both cities (Sopron and Szombathely) are characterized by more green areas and fewer industrial zones (only 2–2 industrial parks due to city locations). The diverse industrial structure of Székesfehérvár is provided by nearly 12,000 companies operating in the city. Among the largest companies, the most significant processors of the Hungarian aluminum industry must also be mentioned. Sectors represented in the settlement include: materials technology, mechatronics, machine/component manufacturing, electronics, informatics, and the food industry. In contrast, Sopron and Szombathely can be characterized by light industrial activities and tourism. In Szombathely, the Cu values did not exceed the pollution limit (40 mg Cu/kg), but extreme limit excesses (e.g., 130 Cu mg/kg) were characteristic in viticulture and garden areas of Sopron. Pb pollution was higher in Sopron soils than in Szombathely soils, but Pb accumulation was characteristic in the eastern part of Szombathely, where intense industrial and transportation activities occurred. Based on the results of the suburban sites, the Zn results were higher in the urban area of Szombathely, where intensive agricultural activity is still an ongoing process [37]. In other Hungarian contexts, trace metals in green fields were measured in Szeged, which proved to be less contaminated with Cd (0.21 mg Cd/kg on average) and Zn (14.49 mg Zn/kg) [76].

4.2. Soil Microarthropods and Soil Biological Quality

Urban soils can be considered a sink for pollutants, including trace metals [77,78]. Pollution can affect soil organisms directly and indirectly. Soil microarthropods come into direct contact with contaminants through their consumed food [79]. In urban soils polluted with trace metals, toxicity for soil-inhabiting animals is mainly related to pollutant concentration in the pore water [80–83]. However, the total concentrations of heavy metals linked to the soil solid phase might also contribute to contaminant uptake by specific groups of soil microarthropods [84,85]. The studied microarthropod groups have specialized morpho-physiological systems for absorbing water, like the water-conducting system unique to Isopoda; the rectal uptake systems in Diplopoda; the ventral tube in Collembola; or the eversible bladders in Diplura, Pauropoda, Protura, Symphyla, and Thysanura [79,86]. Indirect toxic effects of urban soil contamination may also be related to changes in food resources and food webs or to the physical changes in habitats [22,79,84]. A decrease in the number of microbial populations or the quantity of fungal hyphae as a response to soil contamination can change Collembola communities by affecting groups feeding on soil fungi and bacteria [87]. The hyphae of fungi may accumulate extremely high metal concentrations in urban environments [88–90]; consequently, fungi are an important route for food chain transfer of metals through their consumers, such as Collembola, all the way through to their predators, e.g., specific groups of Pseudoscorpionida, Araneae, Acari, and Coleoptera [91].

In our study, the soil of the sites sampled differed widely both in microarthropod abundance and taxa richness. Although we found the highest total abundance in a less polluted site (S145), no correlation was observed with soil trace metal content, suggesting that total abundance is an unsuitable characteristic for assaying metal pollution [92,93]. Certain species or groups that are more tolerant to trace metal pollution can benefit from the disappearance or abundance decrease in less tolerant sensitive taxa, compensating or even over-compensating the number of individuals [94]. The two ubiquitous taxa, Acari and Collembola, occurred in relatively high numbers in all samples and are, therefore, unsuitable indicators of soil condition differences at the group level [19,95]. Acari represent a major arthropod group, the one found to be the most abundant in every site. Though metal pollution can negatively affect the abundance and composition of mite communities (e.g., [96–98]), the discovered mite communities proved quite tolerant to trace metal pollution. From the mentioned ubiquitous taxa, Collembola showed higher variation in abundance among the studied sites and, as the CCA ordination revealed, showed slight sensitivity to the content of certain available trace metals (Cu, Zn, and Pb). However, for a more accurate evaluation, the necessity of species-level analyses cannot be neglected [22,23]. On the other hand, the behavior of rare microarthropod groups can provide useful information on soil condition and health even at a higher taxonomic level [19,93]. According to our results, Symphyla, Pauropoda, Chilopoda, and Diplura appeared to be the most sensitive groups. However, Protura, Isopoda, and Pseudoscorpionida also showed avoidance of soils with higher concentrations of Cu, Zn, and Pb. Nevertheless, available information concerning the metal tolerance of the mentioned groups is limited. In agreement with our results, some authors [93,99] observed a decrease in Symphyla abundance in trace metal-contaminated soils, while other studies [19,100] found this group rather tolerant to metals. In sound agreement with our results, Protura appeared to be particularly sensitive to metals in a lead-polluted area [101]. With regard to Isopoda, several authors (e.g., [102,103]) noted that the absence or decreased abundance of this group is mainly related to the increased content of Zn. Our findings also support this. On the other hand, it is worth noting that isopods are capable of accumulating heavy metals [104,105] and can, therefore, also occur with considerable abundance in urban environments [19]. Bogyó et al. [106] reported on the significant impact of urbanization on Diplopoda communities. Diplopoda were sampled in only two sites in Székesfehérvár, although one of them (site S99) presented relatively high Pb, Cu, and Zn concentrations. Hymenoptera, mainly represented by Formicidae, which show relatively high tolerance to metal pollution, occurred in all sampling sites except two. Similar results were obtained by McIntyre et al. [95] and Eeva et al. [107]. By contrast, Santorufo et al. [19] found Formicidae to be sensitive to metal contamination in their study, which was executed in a Mediterranean city.

The diversity measurement (Shannon index) used showed low taxa diversity in two sites with higher available Cu, Zn, and Pb concentrations, but the opposite (relatively high diversity in a polluted site) was also observed. As several authors emphasized, no evident relationship between diversity and trace metal contamination exists; therefore, diversity measurement indices should be applied with caution when evaluating pollution [19,105,108].

The advantage of the QBS approach lies in taking into account the functional role and adaptation level of organisms of different trophic levels, which makes it a useful method to evaluate soil degradation [64]. The QBS-ar indexes obtained showed high variation among the studied sites, with the highest values associated with less-polluted soils. Usually, a more stable soil environment is characterized by QBS-ar values between 100 and 200 [109]. The higher values in the central area of the city (sites S35 and S145) might indicate isolated habitat remnants of favorable conditions where soil organisms are able to tolerate a greater degree of urban development and pollution [18].

5. Conclusions

Székesfehérvár is surrounded by agricultural lands; thus, toxic elements also possibly exist in the suburbs due to fertilization. The city has several busy roads. Consequently, large amounts of Pb, Zn, Cu, and Cd are expected in the traffic zones and green spaces. In addition, the M7 motorway passes through the township from the south side. Therefore, an extremely high trace metal occurrence was expected. The soils were mostly alkaline; hence, high $CaCO_3$ was typical. Available toxic elements (Cd, Co, Cu, Ni, Pb, and Zn) showed extremes in the case of Cu (value: 408 mg Cu/kg, interventional pollution limit C1 $\geq$ 90 mg Cu/kg) and Zn (value: 47.54 mg/kg, interventional pollution limit C1 $\geq$ 40 mg Cu/kg). Based on these previous findings, sharp increases were expected between the samples of 2011 and 2018. In 2018, samples taken alongside busy roads—especially near the M7 motorway or other busy roads—were contaminated with Zn and exceeded the "C1" limit (>40 mg Zn/kg) and "C2" limit (>80 mg Zn/kg). The Pb concentration decreased slightly towards the peripheral areas in the southern part of the city. Near the M7 motorway, the most polluted sites were detected, and moderate enrichment was calculated. In addition, the trace metal content of green areas definitely increased. Evaluation of soil biological quality showed that soil biota has clear responses to the degree of trace metal pollution in urban environments. Sites characterized by high metal concentrations are usually associated with lower diversity and QBS-ar values. Important groups such as Symphyla, Protura, Pauropoda, and Chilopoda were completely absent from the most polluted sites. Nevertheless, higher QBS-ar values were also obtained in a few city center sites, indicating stable soil ecosystems.

The novelty of the present study is the fact that not only chemical but also biological surveys and thus a more complex evaluation were performed. There was a demonstrable correlation between specific chemical parameters and soil microarthropod groups. Analyses complemented with biological indices related to, e.g., aquatic macroinvertebrate and soil mesofauna communities can detect all prominent anthropogenic influences in the urban environment. The close relationship between biological and chemical properties suggests the necessity of similar soil biological monitoring in the future in urban environments.

In summary, our results have shown that soils were generally more polluted in 2011. Currently, Székesfehérvár is a livable urban environment, one which is still being formed, but is developing in a suitable way.

Author Contributions: Conceptualization, A.H., A.B., and D.W.; methodology, A.H. and D.W.; software, P.B.; validation, Z.G., P.K., and R.S.; formal analysis, D.W.; investigation, B.B.-V., A.H., and D.W.; resources, P.C.; data curation, P.K.; writing—original draft preparation, A.H. and D.W.; writing—review and editing, A.H. and D.W.; visualization, P.B.; supervision, A.B.; project administration, A.H.; funding acquisition, A.B. All authors have read and agreed to the published version of the manuscript.

Funding: This article was written in the framework of the "EFOP-3.6.1-16-2016-00018—Improving the role of research+development+innovation in the higher education through institutional developments assisting intelligent specialization in Sopron and Szombathely".

Acknowledgments: Special thanks to Tamás Hofmann, Frank Berger, and all of the project contributors.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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