

Urban soil resources of medium-sized cities in Poland: a comparative case study of Toruń and Zielona Góra

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Abstract

Purpose Despite the many studies of urban soils, a comparative analysis for cities of a similar size has not yet been conducted. Thus, the aim of this review paper was to compare the soil distribution patterns in the area of two medium-sized Polish cities (Toruń and Zielona Góra). The authors attempted to answer the question of how natural and technogenic factors contributed to the transformation of urban soils and what the similarities and differences are between these two studied cities.

Materials and methods First, both the natural and the human-related (including historical) factors influencing the soil formation in the studied cities were analysed. Then, a comparison of the degree of transformation of the urban soil environment was presented. The data obtained by the authors during nearly two decades of research (over 200 soil profiles) were used.

Results and discussion Intensive development of the built-up areas in Toruń brought heavy and long-term transformations of soils, which demonstrate the typical properties of Urbic Technosols, Ekranic Technosols and other technogenic soils. Zielona Góra showed a similar state of soil transformation over a considerably smaller area. Currently, the differences

in the soil properties in many built up areas have been blurred, despite the habitat and historical base. The similarities of the soil properties concerned, in particular, a high content of skeletal remains (from a few to over 30%), elevated pH (in KCl) values (even above 8.0) and the artificial soil horizons formation. Both cities struggle with similar problems regarding the changes in the land use within the areas covered by these soils. **Conclusions** It was found that, despite the significant habitat and historical differences between the two studied cities, most of the urban soils, especially Urbic Technosols, Ekranic Technosols and Regosols (Relocatic and Technic), are characterised by similar morphology and properties. The most important differences are the time and scale of the area transformation, which influence the extent of Technosols and Anthrosols within the city borders. The most distinct differences concern the natural and slightly transformed soils, which are the results of various soil-forming factors.

Keywords Human impact · Medium-sized city · SUITMAs · Technogenic materials · Technosols · Urban soils

1 Introduction

The world has experienced an exceptional growth of urbanisation over the last decade. At present, approximately 52% of the world's population and 73% of the European population are urban dwellers. According to forecasts, in 2050 these indices will reach 70 and 86%, respectively (EEA 2010; UN 2012). Today, urban areas cover ca. 6% of the total area of the European continent, and this value increases every 5 years by 0.34–0.50% (UN 2011). The urbanosphere, as a habitat of contemporary cities, is subject to constant changes caused by human impact. Therefore, it is of particular interest to scientists from different fields.

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Soil studies oriented towards urban areas were initiated in the 70s and 80s of the twentieth century (Blume and Sukopp 1976; Blume and Runge 1978; Schröder 1983; Craul 1985; Grenzius 1987; Blume 1989). The subjects of consideration were the causal factors of soil transformations in urban areas and their impact on soil profile structure, properties and classifications (Blume and Sukopp 1976; Schröder 1983; Konecka-Betley et al. 1984; Craul 1985; Grenzius 1987; Blume 1989; Kretschmer et al. 1993; Burghardt 1994, 1996; Czarnowska 1995; Kahle and Coburger 1996; Hiller and Meuser 1998). Some of the analyses, as well as those of a scientific nature, were also of utilitarian nature, related to the generation of soil maps for urban areas. The significant impact of the described analyses on spatial planning and expansion of the cities was demonstrated (Craul 1992; Verheye 1996; Efland and Pouyat 1997). The studies were intensified significantly after the establishment of the SUITMA (Soils of Urban, Industrial, Traffic, Mining and Military Areas) group (First International Conference, 2000, Essen; Eight, 2015, Mexico). From the very beginning, a great deal of attention was paid to the issues of the methodology and research techniques (Ge et al. 2000; Sandroni et al. 2003; Davidson et al. 2006; Cheng et al. 2011; Rzaşa and Owczarzak 2013; Vereecken 2016) and anthropogenic soil classification (Efland and Pouyat 1997; Rossiter 2007; Charzyński et al. 2013a). As time passed by, the issues related to Technosols pedogenesis (Lefort et al. 2006; Monserié et al. 2009; Scalenghe and Ferraris 2009; Séré et al. 2010), soils vs. city management and landscape planning (Verheye 1996; Brown et al. 2000; Herrick 2000; Jim 2001; Hanks and Lewandowski 2003; Chen 2007; Vrščaj et al. 2008; Schindelbeck et al. 2008), man-made materials, their features and qualities as soils and parent materials (Pey, Burghardt 1996; El Khalil et al. 2008; Nehls et al. 2013; Huot et al. 2015), soils and the urban ecology (Bullock and Gregory 1991; Bartsch et al. 1997; Chronopoulos et al. 1997; Jim 1998, 2001; Rusakov and Novikov 2003; Bastida et al. 2008; Scalenghe and Ajmone Marsan 2009; Bartens et al. 2010; Pataki 2015) and legal regulations and strategies (Verheye 1996; Huinink 1998; Karlen et al. 2003; Provoost et al. 2006; Bouma and Droogers 2007; Bone et al. 2010) came to be described in more and more detail. The soil cover was studied in many cities of different sizes and geographical, natural and planning specificity (Schleuß et al. 1998; Greinert 2015a; Wiesner et al. 2016). As well as a number of publications regarding the described subjects, the recognition of the geochemistry of urban soils was continued, especially in those centres with heavy industrial and transport pressure (Kelly and Thornton 1996; Birke and Rauch 2000; Sánchez-Martin et al. 2000; Thuy et al. 2000; Manta et al. 2003; Tjihuis et al. 2002; Imperato et al. 2003; Doichinova et al. 2006; Chen 2007; Green et al. 2008; Ajmone-Marsan et al. 2008; Pfeiderer et al. 2012; Charzyński et al. 2013b, c; Kubus et al. 2013;

Kwasowski 2013; Huot et al. 2014). Also, the diverse soils of historic city sectors and historic human settlements were described more and more frequently (Park et al. 2010; Charzyński and Hulisz 2013; Markiewicz et al. 2013; Jankowski et al. 2013).

In the ecological studies, urban areas are described as very complex, especially now, when new, large areas are incorporated into cities. As a result, urban areas have varying features (Cadenasso and Pickett 2008) and are characterised by a complexity in their soil cover (Greinert 2003; Pickett and Cadenasso 2009; Charzyński et al. 2013a). The soils of urban areas can be slightly transformed (without any consequences for the soil classification), or the extent of the transformation is so large that totally technogenic soils develop. Special attention should be paid to the uniqueness of the spatial and vertical distribution of the soil parent rocks and the high contribution of technogenic materials therein. Their properties and a degree of differentiation strongly influence the state of urban soils (Siem et al. 1987; Morel et al. 2005; Pickett and Cadenasso 2009; Huot et al. 2013).

Although many authors emphasize the strong heterogeneity of urban soils (e.g. Gerasimova et al. 2003; Capra et al. 2015; Greinert 2015a), there are only a few comparative studies for cities of similar sizes (Rodrigues et al. 2009), excluding heavy metal content (Ajmone-Marsan et al. 2008). Therefore, the objective of this review paper was to compare the soil distribution patterns in the area of two medium-sized Polish cities (Toruń and Zielona Góra) based on the previously published findings of the authors (Charzyński et al. 2011a, b, 2013a, b, c, d, e; Charzyński and Świtoniak 2014; Charzyński et al., 2015; Greinert 2000, 2001, 2002, 2003, 2013, 2015a, b; Greinert et al. 2013; Piotrowska-Długosz and Charzyński 2015; Mendyk and Charzyński 2016). The general strategy was to investigate various types of technogenic soils to assess the degree of human-induced disturbances. In total, 235 soil profiles were studied during almost two decades in Toruń (130) and Zielona Góra (105).

In this paper, both the natural and the human-related factors influencing the soil formation were analysed. Although the cities have similar historical origins, which date back to the Middle Ages, their development diverged in the centuries to follow. Consequently, two different urban areas have developed, with a different population pattern, a modern internal structure and a configuration of habitat. Therefore, the question arises as to how these factors contributed to the transformation of the urban soils and what the similarities and differences are between the two studied cities. In the author's opinion, the soil cover of medium-sized cities seems to be a better subject for comparative studies than those of large urban centres because the complex changes in the soil environment on this scale are usually easier to recognize and analyse.

Comparative studies which illustrate the soil cover of different cities against the background of local and supralocal

soil-forming factors, necessitates general view of universal soil classifications. This, in turn, is the first step to drawing up comprehensive cartographic documents, understandable by a broad range of scientists and practitioners involved in those tasks related to the protection and development of urban space.

2 Urban soil development in Toruń and Zielona Góra

2.1 Location and natural conditions

Toruń is situated on the Vistula River (Fig. 1), in northern Poland (18° 36' E and 53° 01' N). Three main morphogenetic units can be distinguished within the city borders based on the topography and the types of soil parent material (Kondracki 2002; Bednarek and Jankowski 2006): sandy terraces with vast dune complexes in the eastern part of the Toruń-Eberswalde ice-marginal valley (Toruń Basin), the Drwęca River valley and a small section of the moraine plateau (Chełmno Lakeland). The Holocene age has left its mark on the depositional floodplain, which is made of silty and sandy

deposits. The moraine deposits are tills with a varying content of clay (Niewiarowski and Weckwerth 2006).

The city of Zielona Góra is located in western Poland (15° 30' E and 51° 56' N), on two geomorphological structures: the glacial end-moraine (Zielona Góra Moraine Shaft) and the moraine plateau. The natural city borders are two river valleys—the Oder River from the north and the Ślaska Ochla River from the south. The soils of Zielona Góra are developed from glacial deposits—Weichselian and Riss glaciations and Holocene deposits. The Pleistocene is represented by glacial marly brown till, fluviglacial sandy-gravel sediments, constituents of kame and outwash terraces as well as sands, gravels and boulders of the terminal moraine. The Holocene sediments are represented by peat, chalk, gyttja, fluvial sand and silt, warp (mud), sand, fluvial gravel and silt as well as aeolian sands (Wróbel 1989).

According to Köppen-Geiger's climate classification, Toruń and Zielona Góra are located in the Cfb climate zone, which is generally described as warm temperate, fully humid with a warm summer (Kottek et al. 2006). Nevertheless, there are significant differences within individual regions. The climate of Toruń is characterised by high variation caused by clashing eastern continental and western oceanic air masses.

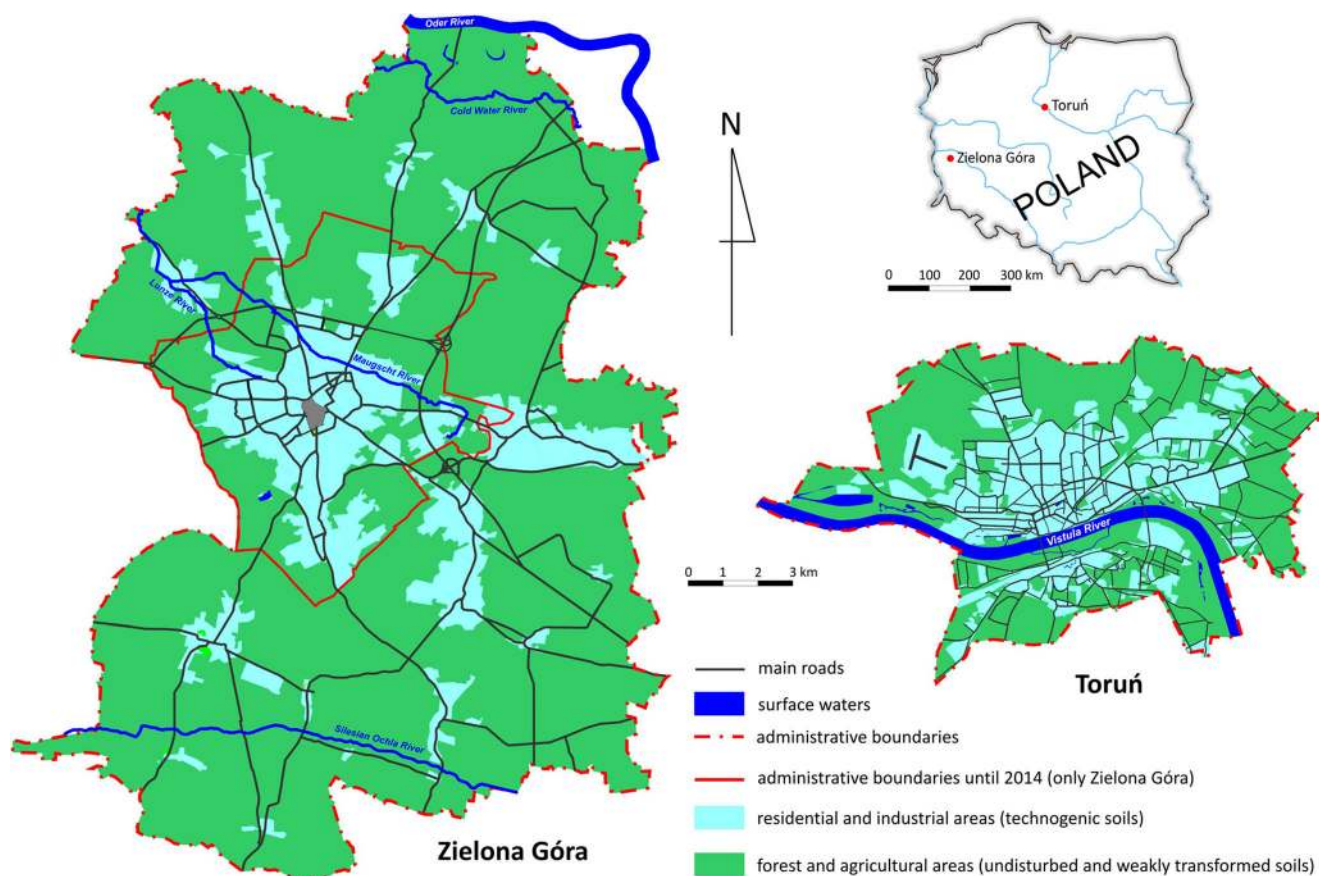


Fig. 1 Location map, administrative borders and land use of Toruń and Zielona Góra

This is due to the geographical location of the city in the Toruń Basin. The mean long-term (1951–2000 yr) annual temperature is 7.9 °C and mean annual precipitation—522.5 mm (Wójcik and Marciniak 2006). Zielona Góra is located in a slightly different mesoclimate compared to Toruń, which results in a warmer climate, a Polish hotspot located just a few dozen kilometres from the city. The climate conditions are characterised by the following indices (1971–2013): mean annual air temperature –8.7 °C, mean total annual precipitation –577 mm (Statistical Office in Zielona Góra 2014).

2.2 Human-induced environmental transformations

Founded in 1233, Toruń is one of the oldest cities in Poland. The origin and development of this city are largely attributed to the favourable geographical location on the Vistula River. In the Middle Ages, it was a prominent trade centre and a member of the Hanseatic League—a confederation of European towns and merchants developed in the thirteenth century. Today, because of its famous gothic urban complex (UNESCO World Heritage Site), the city is one of the most important and crowded tourist centres in Poland. As of 31 December 2014, the population of the city was 203,158 (Statistical Office in Bydgoszcz 2015), which lives in an area of 116 km².

Zielona Góra is a city on the Polish-German borderland (51° 56′ 23″ N, 15° 30′ 18″ E). The first information about the city foundation comes from 1222, but the city rights were probably granted in 1312 (Schmidt 1922). Currently (as of 31 December 2015), 138,711 inhabitants live in Zielona Góra in the relatively large area of 278 km² (Statistical Office in Zielona Góra 2016). Such a large area is the effect of a merger of the city of Zielona Góra (58 km²) with an adjacent rural commune (220 km²) bearing the same name, in the year 2015.

The origin of the land relief transformation in Toruń goes back to the thirteenth century with the highest intensity being in the nineteenth and twentieth centuries. Nowadays, the largest areas in Toruń are represented by flat lands, which have developed as a result of the filling of primary or secondary depressions and the levelling of natural convex forms (e.g. dunes) (Fedorowicz 1993, Podgórski 1996). The thickness of the surface embankments within the administrative boundaries of the city is varied: 1–3 m in the medieval part of Toruń and 3–10 m within the eighteenth and nineteenth century city fortifications (Molewski and Juśkiewicz 2014).

In the nineteenth century, engineering works were carried out on the Vistula River within the Toruń section, and levees were built. The drainage of wetlands was carried out in some districts, which was mostly connected with the construction of fortifications. In the second half of the twentieth century, the groundwater level in the city significantly lowered due to the growth of industry, residential housing and the creation of new water intakes for municipal and residential purposes. For

example, in the industrial, north-eastern part of the city, the water level lowered by more than 3 m (Fedorowicz 1993).

During the Middle Ages, Zielona Góra was surrounded by a wall, first a wooden palisade, then a stone and brick wall. It was demolished in the eighteenth and nineteenth centuries. The whole area after the wall demolition has been occupied by the building structures. Till the end of the eighteenth century, Zielona Góra was a typical small city with a population of 8000 inhabitants, living from agriculture and craft. Very unique in this part of Europe were the vineyards, which existed in Zielona Góra since the foundation of the city, over 4000 ha in the urban and suburban areas in the early nineteenth century (Schmidt 1922; Finke 1924; Bujkiewicz 2011a; Eckert 2011). In 1925, as a result of crop failures and policy change, only 153 ha of the grapevine plantations were left in the region. The remaining lands were transformed into built-up areas, complexes of allotments, parks and other green areas. Intensive industrialization processes took place in the nineteenth and early twentieth century. The main factories in the city were connected with food processing, textiles and the metal industry. As a consequence of this, several industrial zones were established around the entire city (Schmidt 1922; Finke 1924; Czyżniewski 2010; Bujkiewicz 2011b). After 1945, Zielona Góra came under the rule of the Polish State and with time it became a local industrial centre with a population five times higher than when compared to the times before the World War II (Czyżniewski 2010; Bujkiewicz 2011b).

The spatial system of green areas in Toruń has a ring-wedge pattern, which is the result of centuries of human activities related to the economic development of the city. The system consists of an outer ring connected with forest, surrounding the city and the external system of fortifications, an inner ring surrounding the Old Town and wedges, diverse in terms of size and continuity, including the most homogenous zone of greeneries along the Vistula (Urban planning of Toruń 2006). The woodlands are distinguished by the “Kępa Bazarowa” nature reserve with a riparian lowland willow-poplar forest (*Salici-Populetum*), resembling a natural community. The dominant forest community in Toruń includes pine forests with the tree layer composed mostly of planted pine trees of the same age, in some places with an admixture of birch and oak trees. Pine tree stands were also introduced as secondary plantings on military lands, previously deforested during the fortification system expansion in the nineteenth century (Fedorowicz 1993; Rutkowski 2006).

In contrast to the above-described spatial development system of Toruń, no green wedges have been created in Zielona Góra. This was related to the land development of the urban areas and the surrounding arable fields at the expense of forest areas. Consequently, the ring system of greeneries was developed in the city. In the course of the urban development, it has

been gradually replaced by the strip system (Greinert 2015b). Such a system is supported by the geomorphology and hydrography of the city.

The specificity of Zielona Góra consists of a high, almost 50% contribution of forest areas (timber and protection forests) in the total urban area. They are represented by dry pine forests, mesic (fresh) pine forests and mesic (fresh) mixed pine forests, with Scots pine as the dominant habitat types. Additionally, in the areas adjacent to rivers, different habitats such as humid pine forests, mixed forests, humid forests with oak and alder swamp woods are noted (data of State Forest Regional Directorate in Zielona Góra).

The rapid spatial development of both cities disrupted the equilibrium of the habitats in their surroundings, creating comfortable conditions for ruderal vegetation, using nutrients deposited by man in the form of waste. Both in the past and at present, soils have been modified and transformed to create urban greenery. The preparation of these sites for demanding ornamental plant species involves the replacing of the surface soil layer with a garden soil mixture, enriched in organic matter. The soil surface is covered by horticultural fleece and wood chips to facilitate the cultivation. This creates almost entirely different habitat conditions when compared to those existing before the cultivation.

2.3 Land use structure and soil cover patterns

The present state of the urban soils in Toruń is an effect of over 750 years of spatial development and human economic activity. In addition to the location of the city near the important waterway, the area of Toruń is also characterised by favourable geological conditions. Lands suitable for building development are dominant in the area, with a very small proportion of wetlands, while infertile soils facilitate the easy spatial development of the city. A variety of technogenic soils can be found in Toruń: undisturbed and slightly transformed soils, urbisols, industrisols, garden soils, soils of parks and lawns, necrosols, ekranosols, constructosols and edifisols (Bednarek and Jankowski 2006; Charzyński et al. 2013b).

Urban forest soils (Podzols and Brunic Arenosols) cover about 23% of the city area (Fig. 1). They developed from river terraces and dune sands, overgrown mainly with *Pinus sylvestris* stands. Changes in their morphology and properties are often relatively minor. However, the forest soils can be heavily transformed locally by military activity (Jankowski and Sewerniak 2013). Urban agricultural soils (Fluvisols and Fluvisols) are used as meadows, pastures and arable lands. They cover ca. 25% of the city area, but this value is constantly decreasing as a result of urban development (Fig. 1).

More than 50% of the soils within the Toruń city limits are technogenically transformed. Urbisols (Urbic Technosols, Relocatic Regosols) formed in the urban built-up areas are

characterised by varying degrees of morphological transformation. The soils occurring in the Old Town and downtown were formed on a well-developed cultural layer with an urbic horizon of a large thickness and a high content of artefacts. The areas of the relatively new housing estates are covered with incompletely developed Urbisols. The Toruń industry and, thus, industrisols (Spolic Technosols, Relocatic Regosols) are concentrated in three parts of the city—the western, north-eastern and southern areas. Allotment gardens (Hortic Anthrosols, Phaeozems) cover ca. 3% of the total city area. The largest complex occurs in left-bank Toruń, in the Rudak quarter. Garden soils in Toruń cover a slightly larger area because such soils can also be found in the districts of detached houses. Soils of parks and lawns (mainly Arenosols) cover about 2% of the city area (Charzynski et al. 2013d). There are 11 contemporary cemeteries in Toruń. Their soils, necrosols (mosaic of Ekranic and Urbic Technosols and Relocatic Regosols), were researched by Charzyński et al. (2011c). The largest homogeneous area of ekranosols (Ekranic Technosols) in the city is located under the runway and taxiways of the Toruń Aerodrome. Furthermore, ekranosols also occur under all asphalted or cemented streets, sidewalks and alleys in the city parks (Charzynski et al. 2011a, 2013c; Piotrowska-Długosz and Charzyński 2015). Constructosols in Toruń are mainly represented by soils developed on forts (Jankowski et al. 2013) or some medieval walls and soils of older sport grounds. Locally, edifisols (Isolatic Technosols) can be found on some medieval structures and on ruined or badly maintained buildings (Charzyński et al. 2011c, 2015; Charzyński and Hulisz 2013).

Similarly, the nearly 800-year history of Zielona Góra has left its mark on the spatial development of the city. This is observed especially in the city centre. The altitude of the Old Town is currently ca 1.0–1.5 m higher when compared to the ground level of the medieval city, which is caused by the accumulation of various technogenic deposits (Greinert 2003, 2013, Greinert et al. 2013). The small undeveloped fragments are covered by Urbic and Ekranic Technosols (Hyperskeletal). The nineteenth and twentieth centuries brought about the conditions of industrial dominance in relation to the built-up areas of the city, which induced the degradation of the Anthrosols and their transformation into Technosols along with serious contamination (Greinert 2000, 2001, 2003, 2005). The process is accompanied by changes in the land relief, mainly through the levelling of construction sites and the truncation of soils. After the transformations in 1989, the vast majority of industrial enterprises of the city ceased to exist. They were replaced by large wastelands covered with construction debris. New factories were built at the turn of the twentieth and twenty-first centuries, but they did not occupy the previous areas inside the city. New industrial zones were established outside the modern, intensive building developments. They were located on the least productive

soils, which resulted in the removal of all layers of Podzols down to the parent rock. The soils of the new zones are mostly Technic Regosols (Arenic), Greinert (2003).

The large urban areas are currently occupied by residential and commercial housing development. An interesting form of large-scale land transformations were the specific terraces on the northern slope of the Wał Zielonogórski mesoregion (Zielona Góra Embankment), where extensive residential districts were founded for about 50% of the city's population. Currently, the main form of land transformations associated with the described building construction industry are the expansion of residential districts and the intensification of housing developments in historically rural areas, which are being transformed into suburbs with vast complexes of single-family houses.

The contemporary urban area is covered with forests in 45.7% of the city area and 57.4% of the municipal area (Fig. 1). In the forests of Zielona Góra and in the immediate surroundings of the city, the presence of Podzols and Brunic Arenosols is a typical phenomenon. This is a clear result of the pine monocultures as the dominant form of timber forests, which has been observed since the nineteenth century. The soils covering the moraine shaft, i.e. mainly Albic Luvisols, are different. In smaller areas of the city, Luvisols, Albeluvisols, Gleysols and Phaeozems were identified (IUSS Working Group WRB 2007) – Greinert et al. (2013), Greinert (2013).

Along with the inclusion of the commune into the city limits in 2015, the riverside areas of the Oder River, the Śląska Ochla River and their tributaries were also incorporated. The relatively large riverside areas are covered with Fluvisols, Gleysols, Histosols, Phaeozems and locally Stagnosols. Luvisols and Phaeozems occur on slightly elevated grounds, away from the river. Those are mostly agricultural lands. Arable lands, meadows and pastures cover ca. 31% of the total city area. Several distinct changes in the use of the urban and suburban areas have resulted in different transformations of agricultural areas. Changes are observed in the soil

profile morphology, soil physics and chemistry. Most of them are related to typical urbanisation/building activities, or communication and industrialisation. Soils transformed in different ways are present as a result of multilateral human impact: Horticultural Anthrosols, Technic Regosols, Mollic Technosols, Urbic Technosols and Ekranic Technosols (Greinert et al. 2013). A historically unique feature of Zielona Góra, compared to other cities in this region of Europe, was the presence of vast vineyards and orchards almost adjacent to the Old Town. To this day, only a few small vineyards have been preserved, including the Vine Park in the former Grempler's vineyard. Consequently, there are many areas covered with Horticultural Anthrosols, usually transformed by construction activity. The structure of the soil profiles, typical of these soils, has been preserved in parks and allotments.

3 Characteristics of urban soils

3.1 Technogenic parent materials

A characteristic feature of urban regions is the presence of the technogenic parent materials of soils made or transformed by man. Technogenic materials are characterised by a high diversity of constituents, a high spatial variability and a range of temporal discontinuities. Their presence significantly modifies the morphology of soils and their properties. Furthermore, this may be a factor explicitly determining the direction of the soil-forming processes and the evolution of soils (Capra et al. 2015; Greinert 2015a; Huot et al. 2015). The materials of technogenic origin, such as construction debris, slag, dust, rock material, lignite, coal, municipal waste and sludge, are currently considered parent materials for Technosols (IUSS Working Group WRB 2015).

Table 1 presents the properties of exemplary technogenic materials. They are often strongly alkaline, what results from the content of the accumulated construction lime used for the production of construction elements as binding materials and

Table 1 Selected properties of technogenic materials deposited on the soil surface, Zielona Góra (Greinert et al. 2013)

Material	pH in H ₂ O	EC _{1:2} [mS cm ⁻¹]	Fe [mg kg ⁻¹] ^a	Cd	Pb	Zn	Cu	Ni
Neat plaster	11.0	0.6	88.0	0.2	2.8	26	3.7	6.0
Aerated concrete	8.3	0.9	n.d.	0.2	1.7	2.4	1.0	5.0
Roof tile	8.1	2.3	306	0.2	n.d.	34	8.3	2.0
Clinker brick (factory chimney)	7.8	1.1	3750	0.2	n.d.	41	17	1.3
Asbestos-cement roof plank	11.8	4.5	n.d.	0.2	4.6	3.2	5.7	4.3
slag I	8.7	1.3	4150	0.1	19	92	36	16
slag II	7.5	0.7	5410	0.1	22	125	57	18
slag III	9.9	0.8	4960	0.1	n.d.	12	8.0	8.0

n.d. not determined

^a extracted with 0.1 M HCl

plasters, and their presence is linked with all construction work. In the former industrial area of the western part of Toruń, there are extremely acidic deposits in those places where sulphur was stored in the past. Due to the very low buffering properties (non-carbonate sands), their pH was below 1 (Hulisz, unpublished). Some materials such as asbestos-cement roof planks, roof tiles, clinker bricks, factory chimneys and some slag may be characterised by an increased content of readily soluble salts, resulting in relatively high values of electrical conductivity (EC). The analysed materials do not show a high content of heavy metals, potentially available for plants, except for certain types of slag, where slightly higher contents of Cu, Ni, Pb and Zn were determined when compared to other technogenic materials (Table 1).

According to Greinert (2011), the admixture of materials found in technogenic soils can be introduced: at certain, specific spots, by filling various small ground depressions with waste material; over a certain area (regional), by spreading waste materials over the surface of a given area and then covering them with soil and linear, through the partial filling of ditches with waste materials.

This induces an effect of heterogeneous soil properties in urban areas (even small ones). Since a significant part of the waste introduced into soils comprises a dimension of the soil skeleton, they affect the surface soil layers by acting as a drainage medium. The regional and linear introduction of waste leads to the creation of extensive waste layers deposited at varying depths. They act as physical and hydraulic barriers to rooting plants (a dry layer is not easily penetrated by the roots of plants). In addition, they change the flow and deposition of soil solutions, which result in unusual variations in the chemical composition of the soils.

There are very specific features of morphology which are typical of necrosols. According to Gerasimova et al. (2003), they are characterised by the absence of natural horizons, the presence of urban layers with sharp transitions and the presence of anthroskeleton (e.g. fragments of bricks, glass, nails). This was also observed in the soils of Toruń cemeteries (Table 2).

3.2 Soil morphology and properties

Urban soils are frequently characterised by strong horizontal and vertical heterogeneity. The differentiation of the soil sites is significantly related to the site age, human impact intensity and the land use form (Greinert 2015a). The technogenic transformation of urban soils is often evidenced by an artificial profile construction. As a result, abrupt and clear boundaries of layers and horizons prevail in the soil profile. Many soils from the area of Toruń and Zielona Góra exemplify these disturbances. Various types of such transformations can be distinguished, including the most common ones: (i) transport and deposition; (ii) long-term deposition; (iii) mixing and (iv)

Table 2 Types of artefacts in skeleton of necrosol (Ekranic Technosol), St. George cemetery, Toruń (Charzyński et al. 2011b)

Type of artefacts	Horizon		
	Cu 0–14 cm [%]	Au 20–50 cm	AC 50–70 cm
Gravel	37	25	81
Loam	31	–	–
Concrete and bricks	13	72	–
Cinder	9	2	–
Metals	7.5	–	–
Ceramics	1.3	–	–
Plastic	0.5	–	1.0
Bones	0.1	0.2	4.3
Glass	–	0.8	–
Charcoals	–	0.6	14

sealing (Fig. 2). All these can be indicated when classifying soils according to WRB system (IUSS Working Group WRB 2015), using such qualifiers as Transportic, Ekranic, Urbic or the newly introduced Relocatic.

Mechanical transformations of the soil profiles are often accompanied by a significant variability in their physical properties, including common compaction of the soil material. While the surface layers are loose or scarified (due to mechanical cultivation and enrichment with organic matter), deeper soil layers are compacted (Fig. 3). This is a result of the heavy construction equipment used at various stages of the urban development. Although loosening of the topsoil enables grasses and other low plants to take root, it is not sufficient for plants with roots developing to greater depths. Mechanical transformations are accompanied by a number of chemical and physicochemical transformations, caused by e.g. enrichment with a different soil material, organic matter, artefacts, etc. (Fig. 3). These accompanying transformations may also occur irrespective of mechanical changes (Greinert 2005).

Greinert (2003, 2011) determined that the bulk density of mineral soil horizons in the area of Zielona Góra is in the range of 1.4–1.8 g cm⁻³. This parameter was even higher in Toruń, i.e. up to 1.9 g·cm⁻³. Relatively higher values, when compared to the surface layer, were determined in both cities at a depth of below 20 cm (Fig. 3). This is a typical indication that construction work was completed with the preparation of the soil for grass seed sowing (reclamation of the surface soil, organic fertilization). Jim (1998) described the soil structure of many urban areas as mechanically disturbed and contaminated with waste deposition. The author also observed that two thirds of the soil samples from urban areas have a bulk density greater than 1.6 g cm⁻³, the threshold value for successful plant rooting.

Fig. 2 Various types of morphological transformation in urban soils (Regosols and Technosols)



The ranges of such soil parameters as skeleton percentage, content of organic carbon and carbonates and pH in KCl are very similar in two studied cities. Therefore, the data are presented together, independently of the soil location (Table 3). The obtained results suggest that the heterogeneity of urban technogenic soils may reflect a different approach to urban architecture at different stages of historical development.

The observed relationships result from different construction technologies, as well as different construction materials used. The presence of skeleton may seem a very labile feature in almost each of the analysed periods. However, this should be interpreted both in the context of the materials used in the process of construction and the remains left in the soil after former demolitions. Therefore, relatively large amounts of

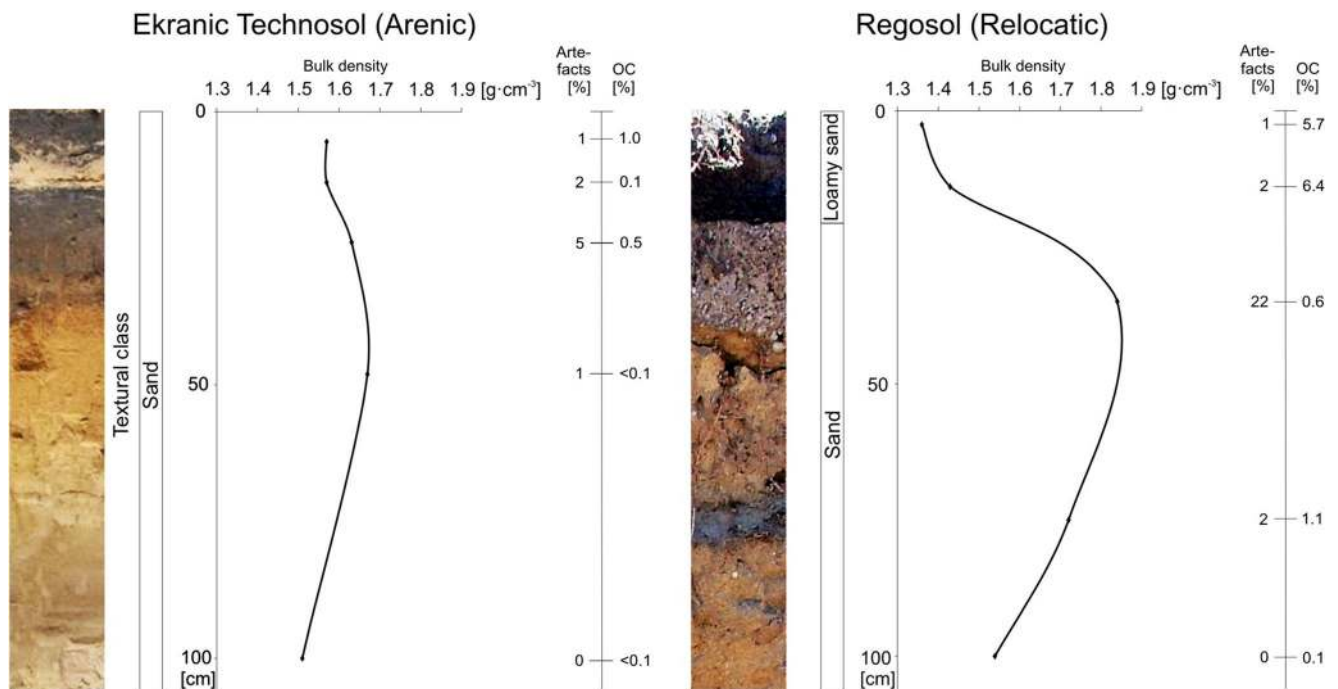


Fig. 3 Variability in the bulk density of selected urban soils in relation to soil texture, organic carbon (OC) and artefacts content: left profile - Toruń (Charzyński et al. 2013e), right profile - Zielona Góra (Greinert et al. 2013)

Table 3 Basic properties of Technosols in the urban area of Zielona Góra and Toruń in relation to the age of buildings (Charzyński et al. 2011a, b, 2013a, c, d, e; Greinert 2013; Greinert et al. 2013; Charzyński and Świtoniak 2014; Charzyński et al. 2015; Greinert, 2015a, b; Piotrowska-Długosz and Charzyński 2015)

Age of building	Number of profiles	Skeleton ($\varphi > 2$ mm) [%]	CaCO ₃	OC	pH in KCl
Before the 19th C.	14	5–46	1.6–3.7	0.2–5.5	5.7–8.2
The 19th/the first half of the 20th C.	20	4–5	0.0–3.4	0.4–3.3	3.9–7.5
The 1950s–1960s	21	2–40	0.4–3.5	0.3–1.7	3.8–7.0
Contemporary–dense building development	33	0.4–80	0.8–1.2	0.1–4.6	3.8–7.5
Contemporary–loose building development	17	0–59	0.2–1.5	0.5–5.0	3.2–5.1

debris have been found in the soil of the oldest areas (demolition deposits) and those developed in the 1970s–1990s (contemporary dense building development) as evidences of the wasteful use of construction materials. By the end of the 1960s, more lime-based materials were used, for example, thick layers of plaster and mortar, resulting in a relatively higher content of CaCO₃ in the soil. It is difficult to clearly interpret the impact of human activities on the total carbon content because of frequent reclamation works carried out in the past and at present in various historical sectors of urban areas. The oldest areas connected with strict city centres are more alkalized when compared to others. This was caused by the direct impact of construction materials as well as the frequent fires of old wooden buildings (the alkalizing effect of ashes). An interesting point of consideration in this regard is a relatively small change in the soil pH of modern, scattered single-family housing construction. This is a consequence of both the economic use of construction materials as well as the partial replacement of the surface soil layers, after completion of a construction project, with waste-free soil, a typical operation of property owners (Table 3).

One of the most commonly observed differences between the urban soils and soils of natural genesis is their pH.

Analysis of the surface layers of the studied soils showed that merely 21.9% of the layers were neutral and 9.4% alkaline. In the case of the deeper layers, often enriched with alkaline materials (construction site wastes), it was 24.4 and 50.7%, respectively (Greinert et al. 2013). Obviously, the differences in the pH values are also associated with the type of land use. The data presented in Table 4 clearly demonstrate frequent transformations of soils, the effects of which overlap. The soils of both urban areas, which based on the morphological properties can be classified as presented taxonomic units, are characterised by physicochemical and chemical properties in similar ranges (as in Table 3). Only some of the properties are very clearly different, such as the content of skeleton in some Ekranic Technosols (the effect of using stones and gravel for road foundation), the lack of skeleton in Linic Technosols (due to the fact that they are artificial soils, built of homogeneous, usually fine-grained natural material; Jankowski and Sewerniak 2013), the very high content of organic carbon (OC) in some Isolatic Technosols (resulting from considerable accumulation of plant remains), Charzyński et al. (2011b), Charzyński and Hulisz (2013), Charzyński et al. (2015) or the high content of CaCO₃ in some Ekranic Technosols (the effect of using mixtures of cement, lime and ash to bind the

Table 4 Basic properties of 0–100 cm layers of Technosols in the urban area of Zielona Góra and Toruń in relation to the soil type according to WRB 2014 (Charzyński et al. 2011a, b, 2013a, c, d, e; Greinert et al. 2013; Jankowski et al. 2013; Charzyński and Świtoniak 2014; Charzyński et al. 2015; Greinert 2013; Greinert, 2015a, b; Piotrowska-Długosz and Charzyński 2015)

Soil units	Number of profiles	Skeleton ($\varphi > 2$ mm) [%]	CaCO ₃	OC	pH in KCl
Urbic Technosols	45	7–11	0.0–1.0	0.4–2.6	6.0–8.3
Isolatic Technosols	10	0–28	<0.1–5.1	1.0–40	6.0–7.8
Ekranic Technosols	34	0.3–36 (96)*	0.0–25	<0.1–5.1	4.7–8.6
Linic Technosols	3	0	0	0.5–4.4	4.7–8.0
Regosols Relocatic/Technic subunits of other RSGs	26	1–19	0.0–3.7	0.2–6.4	5.9–8.2

* for Zielona Góra

soil for road foundation). Some Ekranic Technosols and Linic Technosols also have a relatively low pH, reflecting the property of the only slightly altered parent material of the soils.

Large amounts of halite (NaCl) as well as smaller amounts of other types of salt: CaCl_2 , MgCl_2 and Na_2SO_4 are used every winter to eliminate slipperiness on the roads and pavements, and sometimes also to prevent ice formation on these surfaces. This results in an increased soil salinity in roadside zones, as a consequence of which the vegetation along the roads is exposed to unfavourably high concentration of salts. An increase in salinity is also an effect of the decomposition of municipal and construction waste deposited in the soil. The electrical conductivity (extract 1:2) of soils in Zielona Góra is very seldom above 1 mS cm^{-1} and such a value is recorded only within small areas. It has been found, however, that there is a difference between the average EC for soils inside and outside of the city on average 0.3 mS cm^{-1} compared to 0.1 mS cm^{-1} . Even 2–3 times higher values are recorded in the subsoil when compared to topsoil, which indicates the effect of deposits and the top-down migration of elements. In urban areas, an EC (extract 1:2) below 1 mS cm^{-1} is a typical value described in literature: $0.1\text{--}0.95 \text{ mS cm}^{-1}$ (Madrid et al. 2002), $0.1\text{--}0.6 \text{ mS cm}^{-1}$ (Linde et al. 2001), $0.6\text{--}0.8 \text{ mS cm}^{-1}$ (roadside areas) (Jim 1998) and $0.06\text{--}0.67 \text{ mS cm}^{-1}$ (Ruiz-Cortes et al. 2005), which does not give any cause for

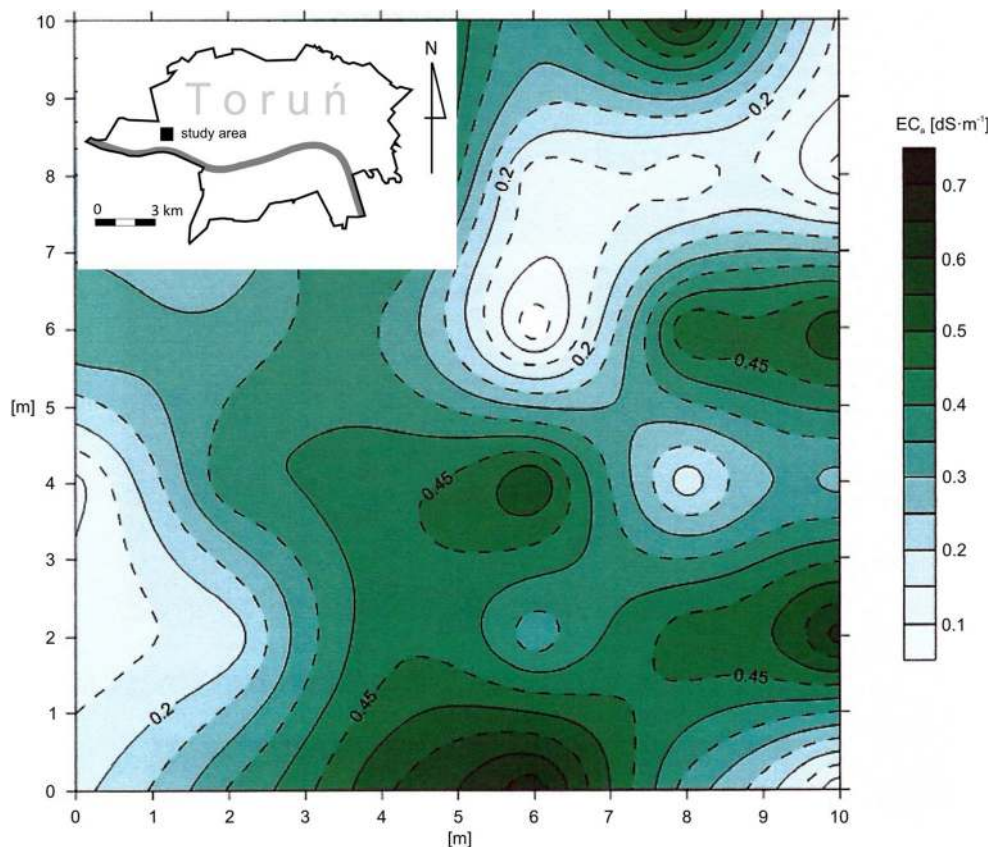
concern about the natural environment (Kotuby-Amacher et al. 2000).

The local-scale variability of soil salinity in the industrial areas is an interesting phenomenon, which confirms the high heterogeneity of urban soils. As evidenced by the research of Piernik et al. (2015), this can be a significant factor for plant species distribution, even over very short distances. Figure 4 shows a map of the electrical conductivity of bulk soil (EC_a ; Time Domain Reflectometry). Despite the very small area of the study plot ($10 \times 10 \text{ m}$) and similarity in soil texture (sand), a large spatial variability of EC values was noted in the 0–25 cm layer. This can be explained by local variations in the microrelief, organic matter and artefact content.

The soils of urban areas can often be characterised by a high content of heavy metals, the main sources of which are industrial wastes, vehicle emissions and coal burning waste (Kabata-Pendias and Pendias 2001; Manta et al. 2003).

The following content of heavy metals (dissolved in 2M HNO_3) was recorded in the lawn soils (Regosols) of Toruń: Cd— $0.2\text{--}1.0 \text{ mg kg}^{-1}$, Cu— $2\text{--}60 \text{ mg kg}^{-1}$, Ni— $3\text{--}23 \text{ mg kg}^{-1}$, Pb— $6\text{--}66 \text{ mg kg}^{-1}$ and Zn— $9\text{--}109 \text{ mg kg}^{-1}$ (Charzyński et al. 2013d). The origin of these pollutants may be associated with elements that often occur in urban soils (pipes, cables, foundations, paints and their components). The specific properties of very shallow soils forming

Fig. 4 Local-scale variability of soil salinity in the industrial area (Toruń) (Hulisz, unpublished)



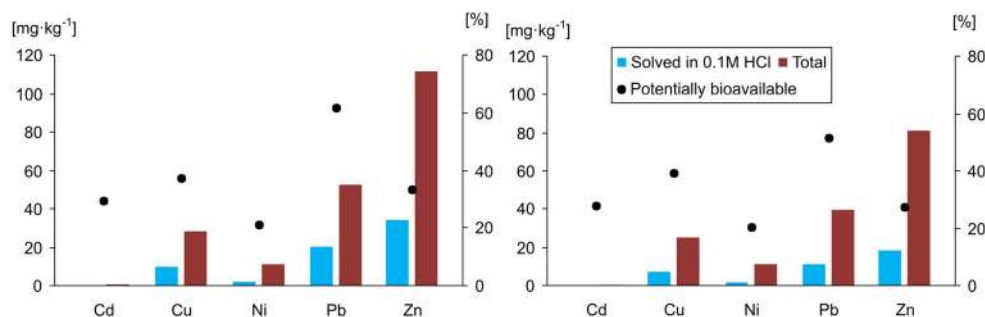


Fig. 5 The content of heavy metals total and solved in 0.1M HCl in topsoil (from the left) and subsoil (from the right). Dots combined with the right scale (in %) are illustrating the bioavailability of heavy metals

calculated as the proportion of the soluble in 0.1M HCl with respect to the total content, Zielona Góra (Greinert 2003)

on building components (walls, roofs and gutters) result from e.g. the input of construction materials, such as plates or wires and the impact of pollutants from the atmosphere. The content of heavy metals is equally varied (total forms in the mixture of acids HF and HClO₃): Cd—<5–18 mg kg⁻¹, Cu—11–110 mg kg⁻¹, Pb—<16–214 mg kg⁻¹ and Zn—72–654 mg kg⁻¹. High pH values (6.4–8.2 in H₂O, 6.0–7.7 and KCl) resulting in the immobilization of some metals are an additional factor responsible for their accumulation (Charzyński and Hulisz 2013; Charzyński et al. 2015).

The soils in Zielona Góra do not usually contain large quantities of heavy metals (Fig. 5). The content of these elements (dry weight) is as follows: Cd—0.2–2.7 mg kg⁻¹, Cu—4.6–192 mg kg⁻¹, Ni—1.2–46.8 mg kg⁻¹, Pb—3.0–241 mg kg⁻¹ and Zn—9–510 mg kg⁻¹ in the subtotal form (aqua regia hot extraction after soil sample dry combustion; Greinert et al. 2013). A higher content of lead and zinc was found in the surface samples, the average values of which were 52 and 111 mg kg⁻¹, respectively. The highest content of Cu was found in the former vineyard areas where the Bordeaux Mixture (usually 0.5% 3Cu(OH)₂·CuSO₄·CaSO₄) was used for decades for fungal disease control (Greinert et al. 2013).

Analysis of the soil properties in Zielona Góra shows a high solubility of heavy metals, which indicates their potential for high bioavailability. This term can be defined as complex dynamic process strongly controlled by the type of organism, type of exposure and metal speciation (Hund-Rinke and Koerdel 2003). A broadly described phenomenon is a clear decrease in the solubility of the majority of heavy metals as well as an increase in pH (Kabata-Pendias and Pendias 2001; Yang et al. 2006; Tack 2010). At this point, it is also necessary to remember the low sorption properties of the researched soils (Greinert 2000, 2003, 2005, 2013). The potential availability of heavy metals (HM) was determined in the surface layers (0–20 cm) of the soil profiles in Zielona Góra, defined as the HM–0.1 M HCl/HM–aqua regia ratio: 29.5% Cd, 37.2% Cu, 20.9% Ni, 61.8% Pb and 33.3% Zn. In the deeper horizons, the ratio has the following values: 27.7% Cd, 39.2%

Cu, 20.3% Ni, 51.6% Pb and 27.4% Zn (Greinert 2003, 2005; Greinert et al. 2013). Lower results were reported by Madrid et al. (2002) in a description of the bioavailability of heavy metals in soil samples collected in Sevilla parks, Spain. The authors found that the ratio of HM–aqua regia to HM–EDTA in relation to Cu was about 15%, to Pb—20% and to Zn—7%. It should, however, be noted that EDTA is a much weaker extractor than 0.1M HCl. More detailed studies were conducted in Canadian cities (Quebec and Hamilton). Ge et al. (2000) found that with a pH values between 6.4 and 7.9, 31.4–59.2% of Cd, 0.01–0.12% of Cu, 0.04–0.37% of Pb and 4.67–21.4% of Zn were present in the dissolved water, and with a pH of 8.4, 7.36–38.9% of Ni was present. Irvine et al. (2009), in turn, regarded the exchangeable fraction and the carbonate-bonded fraction as bioavailable. They laid down a series according to the bioavailability of heavy metals: Zn (28%) > Cd (24%) > Mn (14%) > Pb (12%) > Cu (7%) > Fe (0.3%). The results of soil investigations in New York City, USA by Cheng et al. (2011) demonstrated the same forms as potentially bioavailable, providing, however, a higher value for Pb—33%, a slightly higher value for Cd—28% and a lower value for Zn—19% with acetic acid as an extractor. The authors also determined the correlation between the desorption of heavy metals and the values of soil fractions. In some publications, Cu is also mentioned as a relatively easily exchangeable metal bonded by carbonates even to 68.8%, which can easily be activated by e.g. a change in the pH of the soil (Miretzky et al. 2011). The variations, with reference to the used extractors, extraction conditions and interpretation of results cause great discrepancies in the indications of the potential bioavailability of heavy metals in very diverse (in any case) soils. The obtained results are also influenced greatly by local conditions not related to soil, including the form of land development and the type of soil cultivation conducted. Madrid et al. (2008) noted Cu, Pb and Zn anthropogenic enrichment in clay particles of soils in Torino, but Ni and Cr enrichment in clay particles of soils in Sevilla. Recently, the possible influence of the organic fertilization of soils in urban areas on the bioavailability of heavy metals has also been extensively

described. Murray et al. (2011) noted that the free Cd, Pb and Zn ions were predominant in the garden soils and in the soil with the highest compost amendment. Only Cu had a consistently high proportion bound to organic acids. This may apply particularly to organic matter with a low pH, used for the cultivation of coniferous ornamental plants, but a similar influence of composites in home and public gardens is also described.

4 Conclusions

Toruń and Zielona Góra are cities located in Central Europe, established at approximately the same time. Their diverse history, determined by their locations in relation to the decision-making centres and trade routes, resulted in their divergent development.

Since the early days of Toruń, the intensive development of built-up areas brought heavy and long-term transformations of the soils, which show the typical properties of Urbic Technosols, Ekranic Technosols and other technogenic soils. Zielona Góra, a compact city surrounded by arable fields, for several centuries showed a similar state of soil transformation over a considerably smaller area. On the other hand, much more soils showed properties allowing them to be classified as Hortic Anthrosols and soils of arable lands belonging to the groups of natural soils.

Both cities and their direct surroundings are characterised by different rates of afforestation (55% for Zielona Góra and 23% for Toruń), and thus the soil-protecting land use form and the soil-forming function of dense forest stands are implemented to varying extents.

The transformations of the urban environment in Toruń and Zielona Góra, which occurred after World War II, associated mainly with intensive urbanization, eliminated a number of differences between the cities, not only in relation to the types of transformations and natural conditions, but also their scale. Consequently, both municipalities are covered with soils of similar morphology and properties (especially Urbic Technosols, Ekranic Technosols and Regosols), despite the significant habitat and historical differences. This probably results from the similar techniques and construction technologies used in Central Europe at the time. However, the most important difference is the time and scale of area transformation which influenced the extent of Technosols and Anthrosols within the city borders.

The soils of both cities are currently transformed with a high frequency, which results in the instability of the soil material properties. The changes consist of the partial truncation of soils and the replacement of removed and destroyed layers and horizons by new materials with different properties selected with respect to the target forms of land use—sand, gravel and organic materials for construction or development of

green areas. A most disturbing aspect of this phenomenon is the high solubility of heavy metals deposited in soils.

In order to obtain the probable cause-and-effect relations with reference to the formation of the soil cover in the cities, it is necessary to continue comparative studies. They should focus on the recognition of the factors which diversify the urban soils significantly. A secondary consideration should be the precise specification of the classification characteristics with relation to these soils, which will translate into a coherent system translatable into cartographic documents.

Another direction for the research should be comprehensive studies of the specificity of the urban soils related to the mineralogical characteristics, as well as the forms of respective elements against the parent rock material, soil age, type of transformations and land use.

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