2 URBAN SOILS IN ZIELONA GÓRA

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Introduction

The urban sphere is a complex formation comprising both elements of the natural environment, preserved (usually in a rudimentary form) within the boundaries of a modern city, as well as of the technogenic environment, connected with different types of human activity. With regard to soils, they have been thoroughly analysed for merely a quarter of a century.

According to Blume (1989), there are three basic soil formations in urban areas: soils sealed on the surface, transformed soils with natural development and soils formed from technogenic deposits. Soils with natural profiles are formed mainly as a result of different behaviour of surface and groundwater. This is conditioned by spatial and vertical distribution of chemical compounds and soil-forming materials (Burghardt 1995). The character of urban areas is considerably different from the above thesis. The role of water in the formation of urban soils is strongly limited by truncation of profiles, as well as formation of embankments and excavations, and consequently, changes in the distance between the surface layer and the groundwater table. Changes in the water flow are also caused by isolation of the land surface, the presence of ditches, canals and pipes as well as drainage. The interconnection between particular soil-forming factors is broken. As a result, urban and post-industrial soils merely reflect the history of their use (Pouyat et al. 2009), whereas their genesis is usually quite incomprehensible. This is enhanced by the young age of most urban soils – estimated as several dozen years at most. Most authors notice considerable differences between urban and natural soils in terms of characteristics, including the layout of their layers and levels, chemical composition and structure (Kabata-Pendias, Pendias 1992; Tiller 1992).

Specific soil-forming materials are an important aspect in the discussions of soil scientists on urban soils (Pickett, Cadenasso 2009). Their characteristics and properties largely affect the characteristics and properties of urban soils. Identification of the materials building the urban soils provides a large amount of information about their condition both in the short and long run. This applies to the chemical composition of soils, the behaviour of substances in the soil profile (transport, accumulation, sorption), and transformations caused by different types of weathering. Czarnowska (1995) described the main role of technogenic materials in earthwork soils, and distinguished detailed taxonomic categories: the silicate-rubble-waste subtype, the silicate-rubble-coal subtype, etc.

In terms of transformations of soils resulting from their use, usually the following categories are distinguished: areas used as gardens, parks, cemeteries, housing estates (detached houses and blocks of flats), and communication routes. Apparent differences between the types of buildings constitute an important aspect in the discussion about the influence of the land development type on the behaviour of urban soils. This is indicated by most urban-soil scientists (Burghardt 1996; Hiller, Meuser 1998; Kahle, Coburger 1996; Kretschmer et al. 1993), and also by the results obtained from the research on soils and land in the urban area of the city of Zielona Góra. There are papers indicating that the heterogeneity of urban soils is obvious, which results from the same technologies used for the development of particular areas (Shane 2005). However, most authors regard considerable differences between urban soils as a consequence of single actions in small areas. In this way, areas with a different structure of the soil profile and soil properties are located close to one another. In general, greater variation between soils is described by environmental scientists (soil scientists) than by technical scientists (urban planners).

Study area and soil profile documentation

Zielona Góra is a medium-sized town inhabited by about 110 thousand residents and located in the western part of Poland (51°56’07’’N, 15°30’13’’E). The town’s history dates back to the beginning of the fourteenth century and is related mostly to agricultural and craft activities of the town’s inhabitants. Until the mid-nineteenth century, the small town was surrounded by cultivated fields, gardens and vineyards. Remnants of these activities are present in the residual and surrounding areas to this day. The evolution of the urban territory was limited to the historic centre until the end of the 19^{th} century, after which the character and appearance of the town changed. Strong urbanization and industrialization processes occurred and remained the main mechanism of the area development by the end of the twentieth century. After the political transformation of Poland, Zielona Góra lost its industrial character and became a town with mainly tertiary economy. This involves significant differences both in terms of the scale and intensity of technogenic impact on the environment.

From the geological and geomorphological perspective, Zielona Góra is located in the Middle-Odra-Land, on two geomorphological forms: the Zielona Góra Moraine Belt (max. height 221 m a.s.l.) and the Chynów-Płoty Basin (about 80 m a.s.l.). The moraine belt has a latitudinal shape, and is situated between two main ice marginal valleys: Warsaw-Berlin and Głogow-Baruth (Podgajna 2010). Most of the geological materials building the topsoil of the Zielona Góra locality are medium and coarse sands of glacial and fluvial origin, gravels and in some areas, silts and clays within glacitectonically disturbed moraine structures (Gontaszewska, Kraiński 2007).

Weather conditions are typical of the transition area, influenced by the oceanic and continental climate. During the period of 30 years, the following average values were recorded: monthly temperatures – 9.0°C, min. -22°C (I), max. +35.3°C (VII); annual precipitation – 572 mm (high annual varability – 505–757 mm from 2000 to 2011); the number of rainy days per year – 175.1; winds from the western sector above 50% of the wind rose; wind velocity – 3.2 $m \cdot s^{-1}$, max. 34 $m \cdot s^{-1}$; the number of cloudy days per year – 109; atmospheric pressure – 993.2 hPa, min. 978.9 hPa, max. 1006.1 hPa; snow cover – 50.7 days (Dancewicz 2010).

In the close surroundings of Zielona Góra, the presence of Podzols is a typical phenomenon. This is a clear result of pine monocultures as a dominant form of production forests, which has been observed from the nineteenth century. Forests replaced most of the arable lands and according to the current data, they cover 45.1% of the town and 57.0% of the municipality. Similar processes led to the formation of Brunic Arenosols. In smaller areas, Luvisols, Albeluvisols, Gleysols and Phaeozems were identified according to WRB classification (IUSS Working Group WRB 2007).

Several distinct changes in the use of urban and suburban areas, compared to forest or arable lands, have caused different soil transformations. 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.

Technogenic and anthropogenic soils are present in the area of Zielona Góra as a result of multilateral human pressure (IUSS Working Group WRB 2007):

- Hortic Anthrosols
- Technic Regosols
- Mollic Technosols
- Urbic Technosols
- Ekranic Technosols

The research was carried out in the town and in the administrative commune of Zielona Góra in areas of different use. Particular locations were selected in areas illustrating particular stages of human impact on the natural environment – 105 soil profiles at a depth of 150 cm (samples from each of the morphological layers or genetic horizons) + 32 bulk surface samples (an area of approximately 20 m^2 each, samples from humus horizons). In total, 562 samples were analysed (Greinert 2003). Soils were classified according to WRB (IUSS Working Group WRB 2007) and PSSS (Commission V on Genesis, Classification and Cartography of Soils PSSS 2011) classification. In addition, about 100 other soil profiles were morphologically described up to 2012, taking the opportunity of construction work in the town.

Three selected soil profiles from the Zielona Góra urban area presented in the tables represent different spatial situations and use forms – profile 1 – young town sector, industrial character, created in the late 1960s, about 1 km from the town centre, about 300 m from the main pollutant in the town – a heat and power station (CHP); profile 2 – old town, a few meters from the town hall, with residues of medieval times about 150–200 cm below the present surface; profile 3 – place probably close to the initial location of the town, a productive vineyard till the end of World War II (with no known historical periods of other uses), nowadays the vineyard park, about 500 m from the Old Square (Fig. 1).

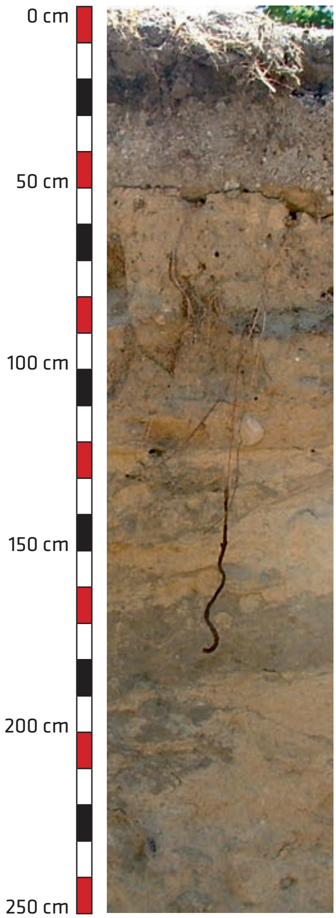
Fig. 1. Location of soil profiles in Zielona Góra

Sorption properties (hydrolytic acidity – HA and total exchangeable bases – TEB) were determined by the Kappen method, pH in H_2O, 1M KCl and 0.01 M $CaCl_2$ – by the potentiometric method; total Ca, K and Na content in aqua regia extract using flame photometry and the TOC content using a Shimadzu analyser. The content of heavy metals in the soil samples was determined by atomic absorption FAAS. Extracts in aqua regia (the mixture of concentrated acids $HCl:HNO_3$ in the proportion of 3:1) were prepared according to ISO 11466 (1995), extracts in 0.1M HCl – the fraction potentially available to plants according to Baker and Amacher (1982). Extracts in 0.1M HCl were prepared and analysed both for the soils and anthropogenic materials. Electrical conductivity (EC) of soil-water extract 1:2 was determined by conductometric method.

All statistical analyses were conducted using Statistica for Windows 9.1a. The basic statistical figures were defined together with correlations between soil condition indices at levels α=0.01 and 0.05.

Profile 1

Location:
Zjednoczenia St.,
Zielona Góra,
Western Poland
Coordinates:
51°56’37’’N
15°29’27’’E
Soil classification (WRB 2007):
Paratechnic Regosol (Arenic)



A1 – 0–5 cm: humus horizon, loamy sand, dark greyish brown, granular structure, dry, few artefacts (glass, plastic and waste organic matter; < 1%), unclear boundary.

A2 – 5–22 cm: humus horizon, loamy sand, dark grey, granular structure, dry, artefacts (pieces of brick, stones, glass, plastic and waste organic matter; 2%), clear boundary.

C – 22–48 cm: mortar-sand-gravel layer, light greenish grey, compacted, gravel and stones > 20%.

IIC – 48–122 cm: sand, light yellowish brown, compacted, dry, interbeddings of loamy sand, stones and gravel (2%), clear boundary.

IIIC – below 122 cm: sand, pale yellow to light grey, single grain structure, slightly moist, without artefacts.

Table 1. Selected soil properties – profile 1

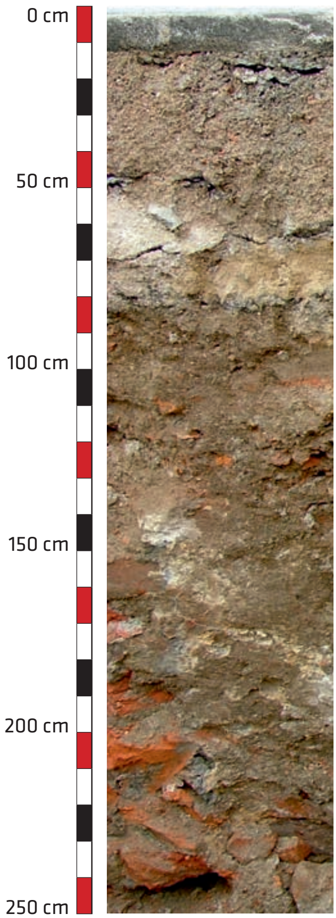
HORIZON		A1	A2	C	IIC	IIIC
DEPTH [cm]		0–5	5–22	22–48	48–122	> 122
PARTICLE SIZE DISTRIBUTION [%]						
>2 mm		<1	2	22	2	0
2 mm–50 μm		81	83	94	96	97
50–2 μm		15	13	6	4	3
<2 μm		4	4	0	0	0
TEXTURE CLASS (USDA)		loamy sand	loamy sand	sand	sand	sand
SOIL MATRIX COLOUR	**dry**	2.5Y 4/1.5	2.5Y 4/1	5G 7/1	2.5Y 6/3	2.5Y 7/2.5 2.5Y 5/1
	moist	2.5Y 3/1	2.5Y 3/1	5G 5/1	2.5Y 4.5/4	2.5Y 5/3 2.5Y 4/1
BULK DENSITY [g·cm^{-3}]		1.36	1.42	1.84	1.72	1.54
OC [%]		5.7	6.4	0.6	1.1	0.1
N_t [%]		0.30	0.29	0.02	0.06	0.02
C:N		19	22	40	20	6
pH	**in H_2O**	7.3	6.9	7.7	7.5	7.2
	in 1M KCl	7.1	6.8	7.3	7.2	6.9
EC [mS·cm^{-1}]		0.46	0.44	0.30	0.29	0.33
CEC [cmol·kg^{-1}]		25.1	21.4	5.6	7.3	3.9
$CaCO_3$ [%]		0.7	0.9	2.7	0.7	0.3
TOTAL CONTENT OF SELECTED MACROELEMENTS						
P [mg·kg^{-1}]		2800	2900	600	130	500
K [mg·kg^{-1}]		10000	10000	5180	4450	6140
Ca [mg·kg^{-1}]		11400	26500	40400	5710	2860

Profile 2

Location:
Old Market Square,
Zielona Góra,
Western Poland

Coordinates:
51°56’19’’N
15°30’19’’E

Soil classification (WRB 2007):
Ekranic Technosol (Arenic)



0–12 cm: concrete slabs, grey, joints filled with cement mortar.

C – 12–50 cm: sand, light yellowish brown, loose, slightly moist, clear boundary.

IIC – 50–80 cm: sand, pale yellow, slightly moist, clear boundary.

IIIC – 80–120 cm: loamy sand, reddish grey, slightly moist, few artefacts (pieces of bricks; 10%), gradual boundary.

IVC – 120–195 cm: sandy loam, brown, slightly moist, artefacts (mortar, brick fragments; 10%), gradual boundary.

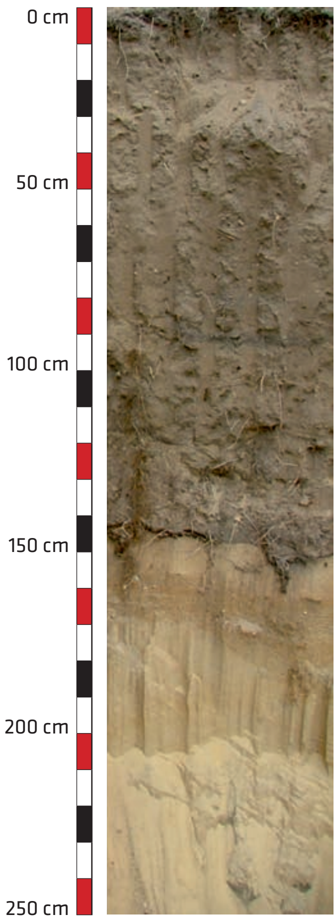
VC – below 195 cm: brick construction dated back to the late Middle Ages, loam, grey.

Table 2. Selected soil properties – profile 2

HORIZON		C	IIC	IIIC	IVC	VC
DEPTH [cm]		12–50	50–80	80–120	120–195	>195
PARTICLE SIZE DISTRIBUTION [%]						
>2 mm		3	1	8	15	87
2 mm–50 µm		96	98	76	73	51
50–2 µm		4	2	22	17	36
<2 µm		0	0	2	10	13
TEXTURE CLASS (USDA)		sand	sand	loamy sand	sandy loam	loam
SOIL MATRIX COLOUR	**dry**	2.5Y 6/3	2.5Y 7/3 2.5Y 8/1	5YR 5/2	7.5YR 5/2	7.5YR 5/1
	moist	2.5 4/3	2.5 5/4	5YR 4/1	7.5YR 3.5/2	7.5YR 4/1
BULK DENSITY [g·cm^{-3}]		1.42	1.53	1.66	1.72	–
OC [%]		0.1	0.0	0.3	0.1	0.0
pH	**in H_2O**	7.5	7.1	7.2	7.1	6.9
	in 1M KCl	7.1	6.8	6.9	6.8	6.7
EC [mS·cm^{-1}]		0.25	0.25	0.24	0.21	0.24
CEC [cmol·kg^{-1}]		5.7	2.6	12.4	15.4	18.1
$CaCO_3$ [%]		2.1	0.6	1.3	4.2	0.9
TOTAL CONTENT OF SELECTED MACROELEMENTS						
P [mg·kg^{-1}]		600	200	1100	1500	900
K [mg·kg^{-1}]		2460	2650	3780	4200	4290
Ca [mg·kg^{-1}]		32000	5800	17100	42000	8900

Profile 3

Location:
Brick Hill; Vineyard Park,
Zielona Góra,
Western Poland
Coordinates:
51°56’15’’N
15°30’43’’E
Soil classification (WRB 2007):
Hortic Anthrosol Arenic)



A1 – 0–5 cm: humus horizon, sand, dark grey, granular structure, slightly moist, very few artefacts (plastic, municipal wastes, glass; <1%), clear boundary.

A2 – 5–145 cm: humus horizon, sand, grey, granular structure, slightly moist, few artefacts (stones; <1%), sharp boundary.

C – below 145 cm: sand, pale yellow, single grain structure, dry/slightly moist.

Table 3. Selected soil properties – profile 3

HORIZON		A1	A2	C
DEPTH [cm]		0–5	5–145	>145
PARTICLE SIZE DISTRIBUTION [%]				
>2 mm		5	0	0
2 mm–50 μm		95	93	95
50–2 μm		5	7	5
<2 μm		0	0	0
TEXTURE CLASS (USDA)		sand	sand	sand
SOIL MATRIX COLOUR	dry	5Y 4/1	5Y 5/1	2.5Y 8/3
	moist	5Y 2.5/1	5Y 3/1	2.5Y 6/3
BULK DENSITY [$g \cdot cm^{-3}$]		1.42	1.51	1.62
OC [%]		5.3	3.3	0.0
N_t [%]		0.38	0.21	–
C:N		14	16	–
pH	in H_2O	6.5	6.8	6.8
	in 1M KCl	6.0	6.3	6.5
EC [$mS \cdot cm^{-1}$]		0.28	0.24	0.06
CEC [$cmol \cdot kg^{-1}$]		22.8	20.6	2.0
$CaCO_3$ [%]		0.5	0.3	0.0
TOTAL CONTENT OF SELECTED MACROELEMENTS				
P [$mg \cdot kg^{-1}$]		3200	2600	600
K [$mg \cdot kg^{-1}$]		10600	8550	4300
Ca [$mg \cdot kg^{-1}$]		26000	22000	2800

Technogenic substrates of urban soils

Technogenic materials present in most urban soils produce lots of pollution, which results from the composition of substrates used for their production and the manufacturing technology (Hiller, Meuser 1998). The content close to general content and potential availability of selected heavy metals from technogenic materials obtained from surface soil layers were analysed in Zielona Góra and nearby settlements. The materials were cleaned of soil without removing traces of lime and cement binding material.

It was found that the analysed materials did not contain large quantities of heavy metals, and they were potentially movable and hence bioavailable (Table 4). This is an important aspect of the discussion about the environmental importance of brick debris in the soils of urban areas. As evidenced by the results of the calcium carbonate content in the analysed materials, there are characteristic changes in the pH of materials, which is an aftermath of not only the construction material properties, but also the amount and the type of binding material present in the brick debris.

Table 4. Reaction (pH values in H_2O), electrical conductivity (EC) and 0.1M HCl extracted heavy metal content in selected technogenic materials deposited on the soil surface

Material	pH in H_2O	EC	$CaCO_3$	Fe	Cd	Pb	Zn	Cu	Ni
		[$mS \cdot cm^{-1}$]	[%]			[$mg \cdot kg^{-1}$]			
neat plaster	11.0	0.63	2.22	88.0	0.18	2.8	25.9	3.7	6.0
aerated concrete	8.3	0.85	2.17	n.d.	0.17	1.7	2.4	1.0	5.0
roof tile	8.1	2.27	2.27	306	0.16	n.d.	33.6	8.3	2.0
clinker brick (factory chimney)	7.8	1.14	2.26	3750	0.15	n.d.	41.1	16.7	1.3
asbestos-cement roof plank	11.8	4.49	2.18	n.d.	0.18	4.6	3.2	5.7	4.3
slag I	8.7	1.30	2.25	4150	0.12	18.5	92.0	35.8	16.3
slag II	7.5	0.70	2.26	5410	0.13	21.5	125	56.7	17.8
slag III	9.9	0.80	2.26	4960	0.13	n.d.	11.7	8.0	8.0

Main characteristics of urban soils

Mechanical transformations of the soil profile are often found in the area of Zielona Góra and its immediate vicinity. In most cases, they are caused by:

– vertical and horizontal mixing of soil horizons and layers;

– admixing of foreign materials to the soil, which are mainly municipal and building waste materials; they are often deposited in layers, which considerably changes the conditions for the transport of water and other components in the soil (Fig. 2–3);
– truncation of the soil profile, mainly by removing the humus horizon, in shallow soils only the bed-rock may remain, so basically no soil is left;
– sealing of the profile with solid materials (bituminous, concrete surfaces, cobblestone or prefabricated cobbles on the cement bed) or loose (organic or mineral) materials;
– compacting the soil layers with heavy construction machines.

Fig. 2–3. Accidental deposition of different technogenic materials induces the formation of unusual soil layers and horizons

Mechanical transformations of soil profiles are often accompanied by considerable changes in physical properties. Excessive density of a large part of soil layers and levels is common (profiles 1–2). Surface layers are loose due to mechanical cultivation and fertilisation with organic matter, but layers situated deeper in soil profiles are often dense and tight (42.5% of the analysed soil profiles in Zielona Góra). This is a result of using heavy construction machines at different stages of the development of urban areas. Loosening the topsoil layer facilitates the rooting of grasses and herbs, but is not sufficient for plants with a deeper root system. Different forms of soil have different water permeability, which means that migrating substances, including nutrients and pollutants, are either retained or infiltrated into deeper soil horizons. This generates problems in plant feeding and reduces the efficiency of reaction to intoxication. A comparison between the compactness of deeper layers in Zielona Góra soil profiles and loosening of the surface layers results in a picture of random land development, focused on a short-term aesthetic effect (Fig. 4–5).

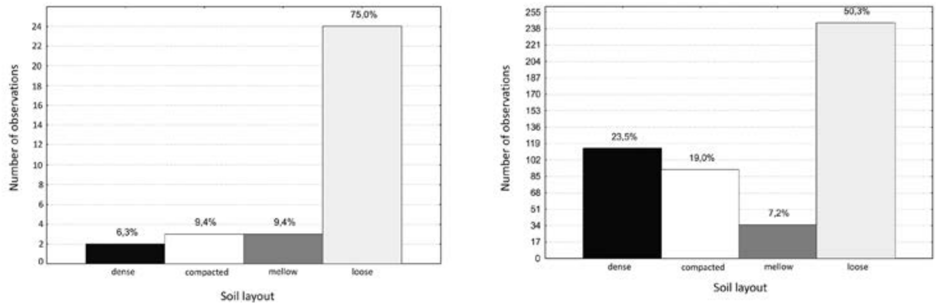


Fig. 4–5. Soil compactness of surface layers, 0–20 cm (from the left) and deeper layers (from the right) in soil profiles; Greinert (2003)

The sand fraction dominates in the particle-size composition of Zielona Góra soils. The average content of isolated fractions from all of the 105 investigated profiles should be presented as follows:

- skeleton 23.5%
- particles < 2 mm 76.5%, incl.:
  - 2 mm – 50 μm 81.2%
  - 50–2 μm 17.8%
  - < 2 μm 1.0%

The skeleton fraction was absent in only 6 profiles. The following texture classes were identified: sand, silt loam, loamy sand, sandy loam (layers in 3 profiles) and loam (layers in 3 profiles). This situation is associated with the genesis of bedrock material and in some cases with the brought-in construction material. Park et al. (2010) observed changes in the particle size distribution correlated with the age of a town. Different relationships have been observed in Zielona Góra. The time when a particular area was incorporated into the town cannot be explicitly related to the above characteristic.

The presence of considerable quantities of brick debris, slag and municipal wastes is a typical morphological feature of soils observed in urban areas, including Zielona Góra. With regard to the development of urban soils, a considerable amount of their additional components is their bedrock.

As evidenced by the analysis of additional components present in the topsoil (0–20 cm) in Zielona Góra, as many as 25% of the soils contain considerable amounts of glass as a result of insufficiently pure municipal waste compost used as a fertilising substance, and uncontrolled deposition of glass. The latter is also the cause of the presence of brick, wood, plastic, lime and cement mortar debris, and undecomposed organic wastes (Fig. 6).

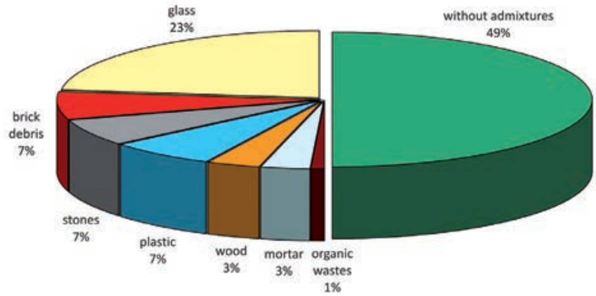


Fig. 6. Admixtures in the topsoil (0–20 cm) of Zielona Góra urban soils (Greinert 2003)

Deeper soil layers have more admixtures than surface layers (61.1%). This indicates that landfill soils have been covered with cleaner materials. This phenomenon is common in the soils of construction sites. In 23.5% of the observations, soils enriched with stones, gravel and sand of different particle size distributions appear to be a consequence of the deposition of unused construction aggregate. Considerable amounts of mixed building rubble, brick debris, cement and lime mortar, building ceramics, concrete, wood, asphalt debris, cobblestone and crushed stone were found in 21.3% of the soil profiles. In general, admixtures of building materials were found in over 40% of the soil layers in Zielona Góra (Fig. 7). This is a typical feature described in the literature by i.a. Pouyat et al. (2007) and Pickett, Cadenasso (2009). Glass and plastic waste was found in 3.3% of the soil layers and horizons. The presence of slag in the described soils is worth mentioning. This results from the fact that in the past, boiler rooms and heating stations discharged the waste in an uncontrolled manner, and alleys and roads were hardened with this material. In only a few soil profiles, clay and silt lenses were found very near brick debris. This results from slaking of these building materials. The extent of transformations of Zielona Góra soils from the group of landfill soils is varied. Therefore, both thick deposits are in the same category, constituting the whole soil profile and partial deposits where brought-in material is deposited in disturbed natural layers or in the undisturbed soil.

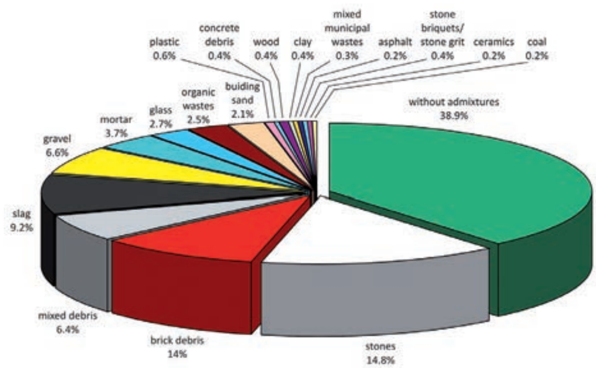


Fig. 7. Admixtures in the soil profiles (0–150 cm) within the Zielona Góra urban area (Greinert 2003)

Profiles of landfill soils are most often characterised by a sharp transition between artificially created layers (43.9%). For this reason, technogenic impact is usually easy to diagnose in the case of urban soils. Clear transition between horizons was found in 38.5% of the observed soil profiles, gradual transition in 16%, and unclear transition in 1.6%.

The functionality of urban soils is mostly conditioned by their sorption properties. In areas of garden allotments, this aspect is additionally connected with the problem of food production. The sorption capacity largely depends on the content of organic matter and the mineral colloids. Admixtures of skeletal parts, such e.g. building material debris, reduce the cation exchange capacity (CEC), which has been confirmed by the research conducted by Hiller and Meuser (1998) on the soils of the Ruhr district. Kahle and Coburger (1996) drew attention to the effect of land use on the sorption capacity of soils. This is related to cultivation or lack thereof, and the depth of mechanical transformation of natural soil. The highest values of CEC were found in the soil of areas with detached houses, which is related to technogenic enrichment of soils with silts, organic matter and clay materials. These techniques are used to achieve good growth of ornamental plants, which require good habitat conditions. A higher capacity of surface layers is typical for most urban soils, with the exception of truncated and mixed soils. In layers situated deeper in the soil profile, the sorption capacity often depends on the covered organic layers and layers of wastes consisting of porous materials (Table 5).

Table 5. Sorptive properties of selected soils within the Zielona Góra urban area (Greinert 2005)

Soil description	HA	TEB	CEC	BS
	[cmol·kg^{-1}]			[%]
initial soils	0.0–2.1	2.3–24.6	3.6–24.6	65–100
rigosols	0.5–0.9	3.6–20.7	4.1–21.6	76–96
treposols*	0.0–4.4	1.9–24.4	2.8–25.2	70–100
hortisols	0.5–1.7	1.6–20.7	2.1–21.4	76–96
landfill soils:				
from bedrock materials without carbonates	0.1–3.3	1.1–24.1	1.6–25.5	32–99
from mixed materials with carbonates	0.2–1.6	2.0–24.7	2.3–26.3	78–99
from mixed materials without carbonates	0.1–11.9	1.4–17.5	1.9–21.8	41–100
from technogenic materials with carbonates	0.0–2.2	0.7–24.6	0.9–25.0	73–100
from brought-in materials without carbonates	0.0–7.2	1.6–24.1	2.4–30.9	63–100
ekranosols	0.1–0.7	2.2–17.0	2.4–17.3	82–99
proper ferruginous soils	1.7–5.1	0.0–5.4	1.9–8.9	0–61
proper podzol soils	0.5–3.3	0.7–1.6	1.1–4.9	32–56

* – according to DBG classification (1998), cited by Greinert (2003)

One of the most common differences between technogenic soils and soils of natural origin is their pH. This is a highly important property from the ecological perspective. The pH level depends on the type of species living in the soil or on the soil surface. During the research on soils in Zielona Góra, fluctuations in pH values were observed. The analysis of surface layers of the studied soils showed that merely 21.9% of the layers were characterised by neutral reaction and 9.4% – by alkaline reaction. In the case of deeper layers, often enriched with alkaline materials (construction site wastes), it was 24.4% and 50.7%, respectively (Table 6). Although alkalization of urban soils causes many problems related to introduction of plants which require acid soil, it has also a number of advantages, which has been confirmed by the research on soil degradation factors conducted by Siuta, Kucharska (1996). It increases the immunity of soils to acidification caused by 'acid rain' and the possibility of stabilising several pollutants (especially lead), which are, in this case, less movable in the soil and are not absorbed by plants.

Table 6. The typical pH values of selected soil groups within the Zielona Góra urban area (Greinert 2005)

Soil description	**pH in 0.01M $CaCl_2$**
initial soils	6.3–7.6 (suburbs: 3.9–4.5)
rigosols	6.0–6.9
treposols*	4.7–7.5
hortisols	6.0–7.7
landfill soil:	3.9–7.3
from native materials without carbonates	3.9–7.4
from mixed materials with carbonates	6.4–7.8
from mixed materials without carbonates	5.2–7.3
from technogenic materials with carbonates	6.6–8.2
from technogenic materials without carbonates	5.4–7.3
ekranosols	6.9–7.4
proper ferruginous soils	3.5–4.2
proper podzol soils	4.1–4.9

* – acc. to DBG classification (1998), cited by Greinert (2003)

Large amounts of rock-salt (NaCl) and smaller quantities of other salts: $CaCl_2$, $MgCl_2$, Na_2SO_4, are used every winter to prevent slipperiness on the streets and pavements, or to remove ice from their surfaces. This causes an increase in the salinity level of the roadside soils. With sandy texture and precipitation exceeding evaporation, salts dissolved in the water are not retained in the soil for a long time, and typical values of electrical conductivity range from 0.03 to 0.39 $mS \cdot cm^{-1}$ in the topsoil to 2.50 $mS \cdot cm^{-1}$ in the subsoil (Greinert 2003). According to the research conducted by Hiller and Meuser (1998), most technogenic materials in urban soils have EC below 1.0 $mS \cdot cm^{-1}$. The authors associated high EC values in soils containing debris with the introduction of gypsum. EC in industrial dusts ranged from 0.7 to 4.0 $mS \cdot cm^{-1}$, and in dusts from hard coal burning - from 0.9 to 6.0 $mS \cdot cm^{-1}$, and brown coal burning - from 2.4 to 3.1 $mS \cdot cm^{-1}$. Dusts from industrial waste burning had high EC values – from 10.5 to 20.2 $mS \cdot cm^{-1}$. It is necessary, however, to notice that soils in the vicinity of Zielona Góra have much lower EC values – within 0.10–0.15 $mS \cdot cm^{-1}$ (Greinert 2003). According to Jackson's salinity scale (Jackson 1958), soils from the Zielona Góra urban area can be classify as non-saline. In such conditions, negative effects should not be observed, even for ornamental plants.

Urban soils are typically enriched with heavy metals. Soils in Zielona Góra do not usually contain high concentrations of elements included in this group. Most of them are present in the soil in the form of salts that can be relatively easily dissolved in water, which means quick migration into deeper layers when the soil is permeable. For this reason, topsoil is not contaminated, despite surface deposition of industrial and traffic pollution. Moreover, the material deposited on the surface of soil profiles is seldom retained for a long time. Rebuilding of the internal structure of the town, both in terms of buildings and streets, results in the excavation of materials which used to remain deeper and introduction of new material from outside the town. This causes a variable distribution of heavy metals in the soils of Zielona Góra. Their content (in dry mass) is as follows: Cd – 0.2–2.7 $mg \cdot kg^{-1}$ (av. 0.4), Cu – 4.6–192 $mg \cdot kg^{-1}$ (av. 24.8), Ni – 1.2–46.8 $mg \cdot kg^{-1}$ (av. 11.1), Pb – 3–241 $mg \cdot kg^{-1}$ (av. 39.5) and Zn – 9–510 $mg \cdot kg^{-1}$ (av. 80) in a subtotal form. Higher contents of lead and zinc were found in surface samples, average values of which were 52 and 111 $mg \cdot kg^{-1}$, respectively. According to the Regulation of the Minister of the Environment (2002), the concentration of heavy metals was higher than the threshold limits defined for soils covering the urban areas only in a few samples – for Cu (threshold values for sandy soils and 0–30 cm layer: 150 $mg \cdot kg^{-1}$, below 30 cm: 100 $mg \cdot kg^{-1}$), for Zn (respectively: 300 $mg \cdot kg^{-1}$ for topsoil and 350 $mg \cdot kg^{-1}$ for subsoil) and for Pb (100 $mg \cdot kg^{-1}$ for topsoil and subsoil). The highest Pb and Zn values were recorded in the roadside areas. The very different situation was connected with the Cu spatial distribution. The highest values were found in the former vineyard areas, where copper compounds were used for fungal disease control. The Bordeaux Mixture (a mixture of copper(II) sulphate ($CuSO_4$) and slaked lime ($Ca(OH)_2$) has been known in vineyards since 1882 as a fungicide to control infestations of downy mildew, powdery mildew and other fungi.

Functional and ecological problems

The main features that influence the assessment of urban soil conditions are as follows: the soil profile morphology, physical properties, salinity, pH, the content of heavy metals and other toxic substances. Each of these features is assessed individually depending on the land use type and indications of environmental risk. In most areas of Zielona Góra, the occurrence of conflicts related to soil profile structure defects and soil properties is not clearly visible. This usually results from the frequent replacement of the surface soil layer with artificial garden soil, implemented at the end of the investment process, which often covers the rock layers of technogenic origin – brick debris layers. They make it difficult for trees and bushes to take roots. Such layers also disturb the circulation of water and minerals. The fashion which has existed for a number of years and consisted in planting of acidophilic plants in urban areas, including coniferous trees and bushes, heathers (*Calluna* sp. and *Erica* sp.), azaleas and rhododendron, has resulted in additional important changes in physical and chemical properties of surface levels. This causes the formation of two completely different parts of soil, usually separated at a depth of 20–30 cm.

Lack of water is characteristic of urban areas, both in the soil and in the form of moisture in the atmosphere. Plants obtain water mainly through the roots from the soil. Water percolating quickly through the soil consisting of brick debris (into the soil below the rhizosphere) is unavailable to plants. This effect is additionally enhanced by construction of buildings and development of infrastructure. Another factor is the sealing of areas of modern cities and draining water from such soils through the rain drainage system (Sieghardt et al. 2005). As a result, almost 50% of the rainfall in the urban environment is biologically ineffective water.

One of the basic problems related to chemical properties of urban soils in the area of Zielona Góra, which is divided by numerous streets and pavements, is the salinization of roadside soils. The salt used in winter for street maintenance prevents the absorption of sufficient amounts of water, which causes the withering of plants, leaf necrosis, premature shedding of leaves, and in extreme cases, the death of plants. However, the duration of salinization varies in urban areas. The worst situation is observed in median dividers, where the soil material is very dense. An increase in salinity is also a result of decomposition of building material and communal wastes deposited in the soil.

Soils in Zielona Góra do not usually contain large quantities of heavy metals. This is partly a result of their high water permeability, and partly low industrialisation. However, the analysis of soil properties in Zielona Góra shows high solubility, which indicates high bioavailability of heavy metals. This phenomenon is interesting in the context of high soil pH. At this point, it is also necessary to remember the disturbances in the structure and low sorption properties of the researched soils. Similar results were reported by Madrid et al. (2008) in the description of high availability and bioavailability of heavy metals in soil samples taken in Torino and Sevilla. Recently, the possible influence of organic fertilisation of soils in urban areas on the bioavailability of heavy metals has also been extensively described (Murray et al. 2011). This may particularly apply to organic matter with low pH used for cultivation of coniferous ornamental plants, but a similar influence of composites in gardens is also described. Murray et al. (2011) described an increase in the bioavailability of heavy metals after the use of compost in the sequence: Cd > Zn > Cu > Pb. Madrid et al. (2008) reported the availability of selected heavy metals in soils in the areas of Torino (T) and Sevilla (S) as follows: Cr 0.6±0.4 (T), 13.1±1.9(S), Cu 50.2±16.5 (T), 16.6±2.6 (S), Ni 7.6±3.1 (T), 2.4±0.5 (S), Pb 47.2±10.2, 18.6±2.7 (S), Zn 19.8±5.9 (T), 54.8±20.3 (S).

Potential availability of heavy metals (HM) was determined in surface layers of soil profiles in Zielona Góra, defined as the ratio HM-0.1M HCl/HM-aqua regia: 29.5% Cd, 37.2% Cu, 20.9% Ni, 61.8% Pb and 33.3% Zn. In deeper layers and levels, the ratio has the following values: 27.7% Cd, 39.2% Cu, 20.3% Ni, 51.6% Pb and 27.4% Zn. The following regularities in the content and solubility of heavy metals can be applied to all soils researched in Zielona Góra:

- content sequence: Zn > Pb > Cu > Ni > Cd;
- solubility sequence in topsoil: Pb > Cu > Zn > Cd > Ni;
- solubility sequence in subsoil: Pb > Cu > Cd > Zn > Ni.

Indications of the so-called ‘hot points' location are important deviations from the trends described in the relevant literature, which is important in terms of urban soil monitoring. In the case of heavy metals, they are always searched for in the emission routes of industrial plants and roads with heavy traffic. A different situation has been observed in the case of roads with the heaviest traffic in Zielona Góra. The concentration of heavy metals in roadside soils is lower compared to other locations. This results from the short exposure time of soils located near the newly built roads. During the construction, part of the material constituting the soils under discussion was brought from clean areas outside the town. The primary soils were also deeply mixed, which caused the effect of heavy metals dilution in the soil mass.

However, hot points in the industrial and post-industrial areas of the town are different in their character; they occur with high density, i.e. close to each other. Due to intensive urbanization of Zielona Góra in the second half of the 20th century, industrial areas previously located in the suburbs or outside the town were included in the urban area. As evidenced by the research performed in the areas of metallurgical and textile industry, power stations, as well as different warehouses and transhipment facilities, there are large quantities of heavy metals and oil derivatives in their soils, down to a considerable depth (Fruzińska 2011, 2012; Greinert et al. 2012).

Classification and cartography of urban soils

Identification of soils and their description, for monitoring or other scientific and practical purposes, requires certain simplification. In this case, classification and mapping of soils in urban areas are the basic requirements of soil science. In the world reference literature, there are different concepts of soil classification in urban areas. The main differences relate to the inclusion of mechanically, highly transformed soils in Regosols, Anthrosols or Technosols (IUSS 2007). Soils in Poland are officially classified according to the Polish Soil Classification, the 5th edition (Commission V on Genesis, Classification and Cartography of Soils PSSS 2011), which divides the anthropogenic soils (Order 11) into four types and 11 subtypes, and all of them are represented in the urban area of Zielona Góra.

Systematics is not an easy issue in soil science, as there are different criteria in different periods of time for defining and assessing particular systematic units. This is closely related to a different approach to soil and its functions, i.e. as one of the components of the ecosystem. Authors of the latest scientific articles often argue that sharp divisions in the classification of soils are incorrect. It should be possible to reflect transitional features of soil profiles and to include one particular soil into more than one unit (Odgers et al. 2011). The problem with classification of soils is even more complicated in the case of urban areas because of their internal complexity, a different scale of transformations and the general complexity of different factors: natural, technogenic, constructional and social (Pickett, Cadenasso 2009). In most cases, there are major differences in the structure of soils with anthropogenic, technogenic and natural genesis. Soils of anthropogenic origin have both pedogenetic horizons and lithogenic layers, or only lithogenic layers. For this reason, it is difficult to adopt a general picture of pedogenetic soil horizons as one of the basics of modern soil classification. In the case of urban soils, modern soil classification must be based on the study of both soil horizons as layers, and technogenesis as pedogenesis (Da-Gang et al. 2008).

Based on the criteria defined by Burghardt (1994), Greinert (2003) classified the soils in the area of Zielona Góra (Fig. 8). This classification includes different forms of anthropogenic and technogenic impact, as well as the genesis and further development of particular soils. Thus, it meets the criteria of the genetic soil classification. According to the principles of the world soil science, this is the primary condition of good classification (Hiller, Meuser 1998; Blume, Runge 1978; Meuser 1996).

This classification was used in the following years as a basis for discussion on the diversity of urban soils. Consequently, the new unit of Edifisols was proposed (Charzyński et al. 2011b) and the new subunit of Carbonate Ekranosols in the type of Ekranosols (Charzyński et al. 2011a).

Soil mapping in urban areas involves specifications of criteria for determination of categories for every piece of data plotted on a map (Blume et al. 1989). Valuable information, resulting from the contents of soil maps of urban areas, includes:

- land use;
- resistance of soils to different forms of degradation;
- risk of plant pollutions;
- risk of groundwater pollution;
- requirements for soil reclamation.

In order to achieve the abovementioned objectives, the concept of urban soil cartography is based on two initial categories – soil systematics and land use. As a result of this approach, different data are associated with basic soil characteristics and planners' functional concepts. This solution also allows the compatibility between studies of urban soils and soil maps of non-urbanised areas in Poland.

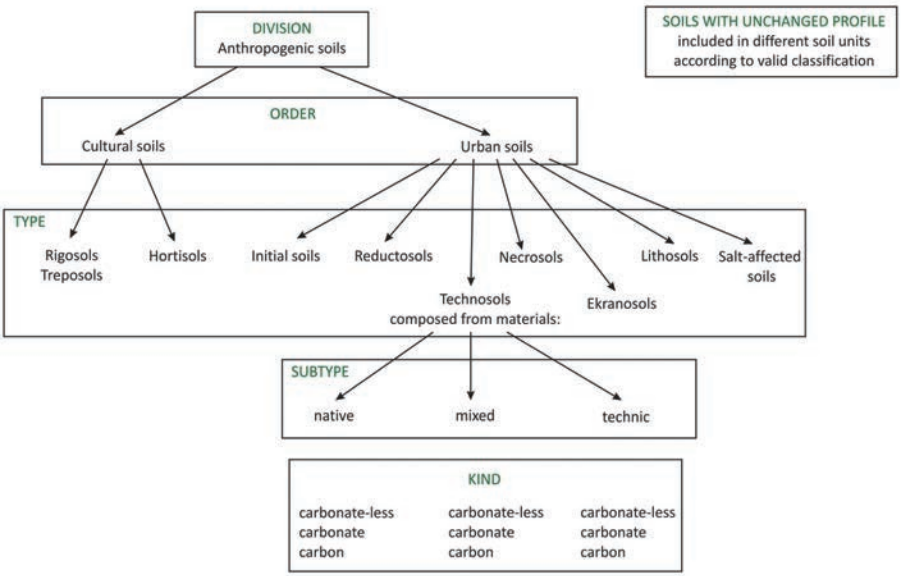


Fig. 8. The concept of urban soil classification (Greinert 2003)

A number of maps of urban areas are large scale maps, which negatively affects their precision. The main problem is to find such an approach to soil research (the basis of soil cartography) as to avoid the excessive complexity of the spatial situation, on the one hand, and to present the true and full information to maps' end-users, e.g. landscape architects, on the other. In the context of these solutions, it is obvious that we are still at the early stage of work on urban soil maps.

Summary

Areas covered with landfill materials are systematically expanding in Zielona Góra, which is caused by quite intensive construction activities. At the same time, areas previously covered with soils with an unchanged or slightly changed profile, mainly in terms of properties and morphological features of surface horizons, are shrinking. There is also a systematic development of construction forms in the area surrounding the town, located within the administrative commune of Zielona Góra. The lands in this area are mostly devoid of soil cover as a consequence of deep mixing of autochthonous materials, the removal of surface layers and transport of materials in the process of investment area levelling.

The course of changes in the soil usually involves the removal of original, useless and barren ground, which is replaced by new material containing humus, brought from other locations (most often, material from topsoil from other construction sites). Special subsoil mixtures, made mainly of composites, peat and bark, are often brought to form a new soil surface layer. The next step is to introduce a barrier for unwanted plants – weeds, mainly by using a non-woven crop cover and bark litter, or by planting a lawn.

The whole area is watered and fertilised, which will lead to changes in the chemical properties of the soil. Unfortunately, in areas of intensive and fast urbanisation, wastes are still managed incorrectly, which results in the presence of brick debris and other waste materials in the soil.

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