Journal of Elementology ISSN 1644-2296

Chudecka, J., Tomaszewicz, T. and Podlasiński, M. (2024)
'Properties of anthropogenic soils of the Old Town and newer parts of Szczecin (Poland), and the possibility of planting trees in these locations',
Journal of Elementology, 29(2), 453-468,
available: https://doi.org/10.5601/jelem.2023.28.4.3154

RECEIVED: 24 October 2023
ACCEPTED: 8 May 2024

ORIGINAL PAPER

Properties of anthropogenic soils of the Old Town and newer parts of Szczecin (Poland), and the possibility of planting trees in these locations*

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Abstract

The aim of the study was to determine differences in the morphology, classification and chemical properties of soils in the city of Szczecin that have been anthropogenically transformed due to their location in an urban area. Soil samples were collected from 22 drillings, with depths of up to 200 cm, in both the Old Town and some newer parts of the city. Various properties were analyzed: the texture, pH in KCl, EC, base cations, and the organic carbon content, as well as the total content of Pb, Zn, Hg, Cd, Cu, Cr, Ni, and Hg. The soils in the Old Town of Szczecin exhibited the most significant anthropogenic transformation, containing anthropogenic admixtures and organic carbon throughout their profiles. These soils were classified as Urbic Technosols (Hyperartefactic) and Skeletic Phaeozems (Technic). The presence of numerous artefacts led to alkalization, high values of the base cations, elevated salinity, and increased content of certain heavy metals. The amounts of Zn, Hg, and Cu in these soils were approximately twice as high, and the Pb levels were seven times higher as the standards allowed by Polish law. Metal pollution in the Old Town area extended to a depth of 200 cm. The soils in the newer areas of Szczecin, which underwent less anthropogenic transformation, contained small amounts of anthropogenic admixtures up to a depth of 45 cm, which is why they did not classify as Technosols. As a result, they were less saline and alkalized, with lower base cations values. Organic carbon was present in these soils to a depth of 60 cm. Pollution with Pb, Cd, and Zn occurred only to a depth of 30 cm, indicating the contemporary origin of these pollutants. When new trees are planted in the Old Town area, consideration should be given to the species of trees that tolerate increased salinity. In newer areas of Szczecin, where salinity is low, all species of trees can be grown.

Keywords: urban soils, artefacts, heavy metals, EC, pH, base cations, organic carbon

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* The work was financed by the Department of Environmental Management's own research.

INTRODUCTION

At present, more than half of the global human population resides in cities and towns – a figure projected to rise to 70% by 2050. Consequently, urban areas are expanding at a greater pace than any other land-use type. Managing urban areas has become one of the most significant development challenges of the 21st century (United Nations, 2019).

The ecological importance of urban soils has long been underestimated. These anthropogenic soils were once perceived merely as substructures of buildings or construction areas. However, they are a crucial and vital component of the urban ecosystem, playing a significant role in human health. Urban soils can be described as former natural soils whose properties have been strongly modified by a wide range of human activities of varying intensities. Therefore, these soils exhibit structures and properties significantly different from the parameters characterizing natural soils (Greinert, 2015, Vogt et al. 2017). City soils are often distinguished by high alkalization and salinity, along with increased levels of heavy metals, petroleum substances, aromatic hydrocarbons, etc. (Horváth et al. 2014, Abel et al. 2015).

The oldest, historical areas of cities are covered by urban soils with strongly changed properties as a consequence of long-term human pressure. These places are characterized by the presence of a thick anthropogenic layer ranging from a few to 10 meters in depth (Aleksandrovskiy et al. 2015, Sedov et al. 2017). The anthropogenic layers/horizons consist of original parent materials or redeposited natural sediments and numerous anthropogenic (technogenic) inclusions, also called artefacts, such as construction debris, ashes, slag, glass, batteries, plastics, metals, textiles, charcoals, organic residues, tailings, and industrial waste materials. Additionally, urban dust, soot, and other materials are often contaminated with hazardous substances, primarily heavy metals. Urban soils are frequently characterized by strong heterogeneity, significantly related to the site age, the human impact intensity, and the form of land use (Pouyat et al. 2007, Greinert, 2015).

The impact of urban factors leads to the progressive degradation of soils and the pollution of water and air, worsening the living conditions of people in cities (Valente et al. 2020). This unfavorable situation could be improved by introducing more urban greenery, especially trees and shrubs. Trees in cities can prevent buildings and surfaces from heating, cool the air, and reduce the wind speed, resulting in an increase in the relative air humidity (Georgi, Zafiriadis 2006). Trees provide ecosystem services by mitigating the urban heat island effect (Shashua-Bar et al. 2009, Bowler et al. 2010), causing air purification, especially through CO_2 sequestration (Szkop 2016, Eisenman et al. 2019) and dust absorption (Sæbø et al. 2003). They also contribute to the reduction of water erosion (Berland et al. 2017), improvement of aesthetics, and enhancement of recreation conditions (Dimke et al. 2013, Bertram et al. 2017).

The careful selection of tree and shrub species from the perspective of their ability to persist under harsh growing conditions is, therefore, very important. This choice must take into account site-specific factors (Sæbø et al. 2003, Vogt et al. 2017, Szkop 2021). Urban greening is currently the most important way to reduce the negative effects of the urban heat island phenomenon and is one of the main tasks of the urban revitalization programs implemented in Poland (Act on Revitalization, 2015).

The aim of the research was to determine the impact of anthropogenic pressure on the morphology, classification and chemical properties of soils located in various locations in the city of Szczecin (Old Town and newer parts of the city). The determined properties of these soils were intended to provide an answer to the possibility of introducing woody vegetation in the urban area to revitalize the urban environment.

MATERIALS AND METHODS

Study objects, soil sampling, and soil material division

The research was conducted in the area of Szczecin, Poland, encompassing its oldest part (Old Town) and its newer areas, which have been subjected to a shorter period of human pressure. The Old Town, inhabited since the second half of the 8th century on today's Castle Hill near the muddy areas of the Odra River, was granted city rights in 1243. This allowed for the integration of the stronghold with the outskirts and the construction of new city walls. The newer districts of the city began to develop at the end of the 19th century when, in 1873, the city fortifications surrounding the Old Town were demolished (Adamczak et al. 1999).

A total of 22 drillings were made in various areas of Szczecin: 14 drillings (No. 1-14) in the Old Town area and 8 drillings (No. 15-22) in the newer areas of the city (Figure 1).

The drillings reached a depth of 200 cm, an auger drill was used. Soil samples were collected from layers/horizons distinguished based on differences in morphology (the color, texture, and content of anthropogenic admixtures).

Materials of natural origin were labeled with the symbol "N". Anthropogenic materials, with visible anthropogenic admixtures, were categorized into two groups: debris anthropogenic materials (AnD) and low-debris anthropogenic materials (An). In AnD materials, anthropogenic admixtures constituted more than 20% of the sample volume, with a maximum of 70% and an average of 50%. The skeleton of these materials was entirely anthropogenic, containing debris with other admixtures, with construction debris usually dominating. In An materials, anthropogenic admixtures constituted a maximum of 20% of their volume, typically ranging from 5-10%. The skeleton

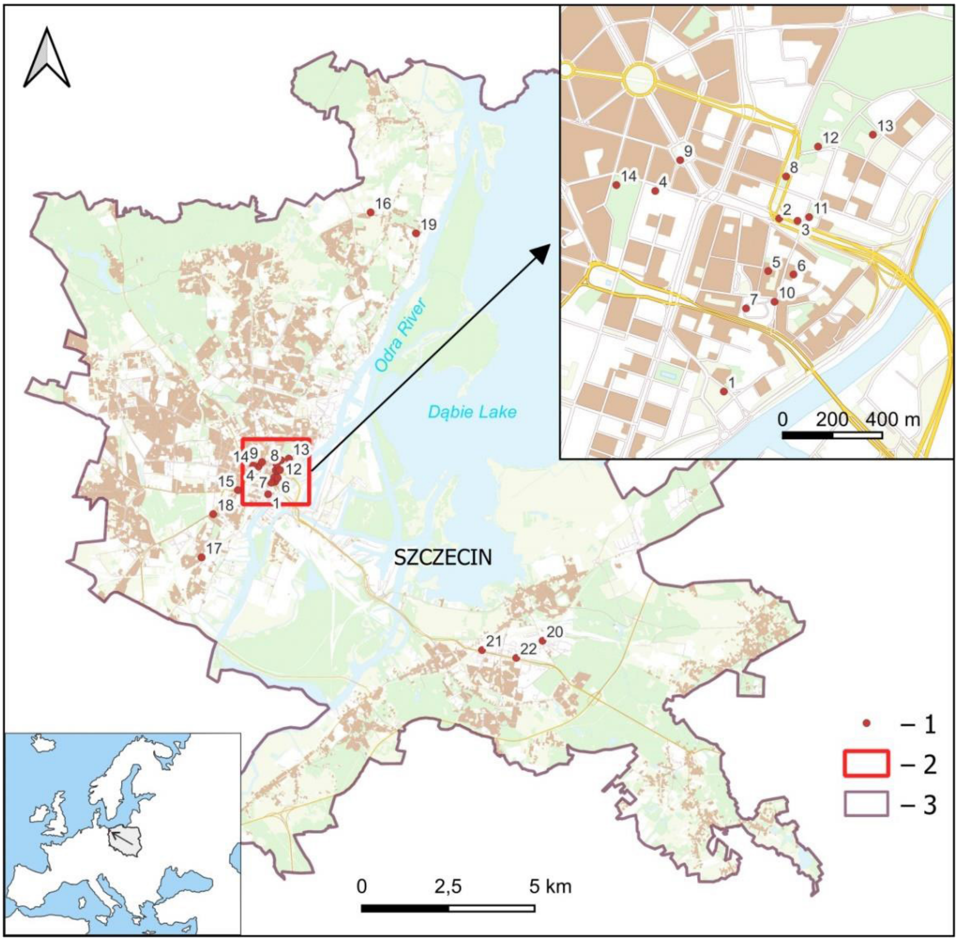

Fig. 1. Locations of drillings made in the area of the city of Szczecin:
1 – drilling number, 2 – Old Town of Szczecin, 3 – administrative borders of Szczecin

of these materials often comprised a mixture of small technogenic admixtures with stones and gravel of natural origin in variable proportions. Sometimes the natural skeleton dominated, but more often, the anthropogenic one prevailed. Among technogenic admixtures, construction debris was rare, and if present, it occurred in the form of small pieces (mainly bricks) that did not dominate the anthropogenic skeleton.

Analyses and calculations

The soil samples were sieved through a mesh with a size of 1 mm, separating the skeleton (>1 mm) from the earth parts (<1 mm).

In the earth materials (particles with a diameter <1 mm), the following properties were analyzed:

– texture was analyzed using the Casagrande method modified by Prószyński. The division of materials into fractions and texture classes was performed according to USDA;
– pH in KCl was analyzed using the potentiometric method;
– electrical conductivity (EC), taken as a measure of salinity, was analyzed using the conductometric method, with a soil to water weight ratio of 1:2.5;
– organic carbon content was determined using the Tyurin's method of wet combustion;
– base cations Ca^{+2}, Mg^{+2}, K^{+}, and Na^{+} were extracted with 1 M ammonium acetate buffered at a pH of 7; the AAS method was used for Ca^{+2} and Mg^{+2} and the AES method was used for K^{+} and Na^{+};
– total content of heavy metals (Pb, Zn, Hg, Cd, Cu, Cr, Ni) was analyzed using the method of plasma emission spectrometry (ICP OES – inductively coupled plasma-optical emission spectrometers) on a JY 24 sequential spectrophotometer, after the mineralization of a one-gram sample in a 1:1 mixture of concentrated nitric and perchloric acids;
– total content of Hg was analyzed with the AAS method using the AMA 245 apparatus.

The organic carbon stocks (t ha^{-1}) were calculated from the organic carbon contents, the thickness of soil layers containing organic carbon, and the bulk density, which was assumed to be at a constant level of 1.5 g cm^{-3}. The calculations took into account the skeleton content (in % by weight) in the layers. The figures were made using the Statistica 14 and Corel Draw 21 programs.

RESULTS AND DISCUSSION

Soil division based on locality, morphology, and texture

The soils of the Old Town of Szczecin were categorized into two groups: group A – soils strongly anthropogenically transformed (9 drillings, numbered 1-9), and group B – soils moderately anthropogenically transformed (5 drillings, numbered 10-14). These soils most commonly exhibited a sandy loam texture, with loamy sand being rare (Figure 2).

Group A, comprising strongly anthropogenically transformed soils, contained anthropogenic materials throughout their entire thickness (up to 200 cm), except for drilling 9 (Figure 2). This group was unique in that it included debris anthropogenic materials (AnD), which formed continuous layers with a maximum thickness of 180 cm or possibly more, as suggested by the situation in drilling 2. In addition to the predominant admixture in the form of construction debris, these soils also contained various other

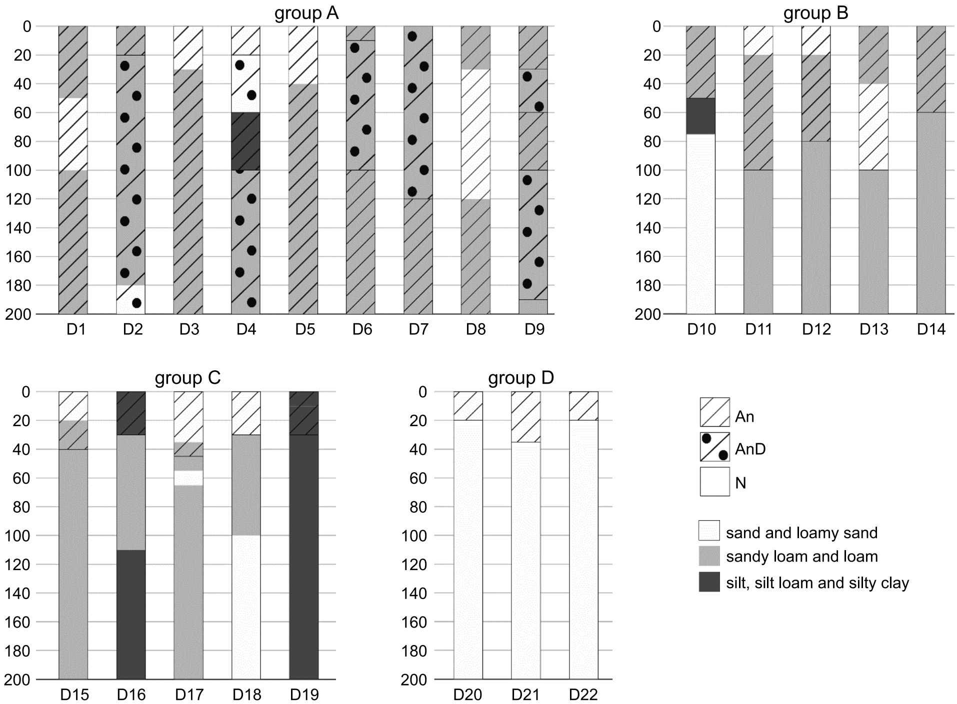

Fig. 2. Morphology and texture of tested soils from the area of Szczecin city A – Old Town (soils strongly anthropogenically transformed), B – Old Town (soils moderately anthropogenically transformed), C – newer areas of the city (loamy soils poorly anthropogenically transformed), D – newer areas of the city (sandy soils poorly anthropogenically transformed); soil materials: AnD – debris anthropogenic materials, An – low-debris anthropogenic materials, N – natural materials, D1–D22 – drilling number

admixtures in significant quantities and often in large sizes, such as slag, burnt wood, charcoal, construction and utility ceramics, glass, porcelain, and bones. These anthropogenic (technogenic) materials, also known as artefacts (WRB 2022), serve as the parent rocks for these soils.

Group B, representing moderately anthropogenically transformed soils of the Old Town of Szczecin, contained a layer of anthropogenic materials 50-100 cm thick, with no AnD materials (Figure 2). The lower level of transformation in these soils, indicated by a lower amount of admixtures and a shallower depth of the occurrence of these admixtures, is attributed to their locations next to old churches and old parks.

The soils from the newer areas of Szczecin, characterized by poor anthropogenic transformation (with the thickness of the anthropogenic layer ranging from 20-45 cm), were also divided into two groups: group C – loamy soils (5 drillings, numbered 15-19), and group D – sandy soils (3 drillings, numbered 20-22). AnD materials were not found in these soils (Figure 2).

According to the World Reference Base for Soil Resources (WRB, 2022), soils from the Old Town area of Szczecin were primarily classified as Urbic

Technosols (Hyperartefactic) – group A and Skeletic Phaeozems (Technic) – group B. In contrast, soils from the newer districts of Szczecin (groups C and D) were classified as Regosols and Arenosols (Humic, Alcalic, or Technic).

According to the Classification of Technogenic Soils in Poland (Kabała et al. 2020), the soils in group A were classified as Urbisols and Aggerosols, those in group B were classified as Aggerosols, those in group C were classified as Regosols (Technic, Humic) and Luvisols (Humic), and those in group D were classified as Arenosols or Brunic Arenosols.

The differentiation of soil sites is significantly influenced by the site age, human impact intensity, and the form of land use. The presence of anthropogenic (technogenic) materials is a key factor that differentiates urban soils the most (Greinert, Kostecki, 2018). Urban soils in older city areas often develop from a mixture of natural and anthropogenic substrates. Disturbances in these soils during urban development involve changes throughout their profiles, including the removal of natural material, which is replaced with foreign material, primarily of anthropogenic origin (El Khalil et al. 2008, Park et al. 2010). Construction debris is the most widespread anthropogenic admixture in urban soils (Greinert 2015, Sedov et al. 2017, Greinert, Kostecki, 2018). A higher percentage of construction debris compared to soil material of natural origin is typical in urban areas (Nehls et al. 2013). Some authors note that the share of anthropogenic admixtures in soils increases as one approaches the historic center, which contains highly modified soils and is surrounded by areas covered by less modified soils. In Berlin, Germany, rubble-composed soils cover about 17% of the total city area and 60% of the inner city (Abel et al. 2015). In the old centres of cities, thick layers from historical deposits and catastrophes can be found (Pouyat et al. 2007, Burghardt et al. 2015).

Organic carbon content

In the soils of group A, organic carbon occurred throughout the entire thickness being studied, up to 200 cm. In group B soils, it was present in materials to a maximum depth of 100 cm, while in the soils in groups C and D, it extended up to 60 cm (Figure 3). As a result, the largest stock of this component (an average of 495 t ha^{-1}) was found in the strongly anthropogenically transformed soils of group A (Figure 4). For soils in groups B, C, and D, the average organic carbon stocks were 200, 135, and 72 t ha^{-1}, respectively. The variation in the percentage content of this ingredient in soil horizons/layers was significant, ranging from low to very high amounts, indicating the mineral-organic nature of materials (Figure 3), which is specific to urban soils.

Research by Aleksandrovskaya and Aleksandrovskiy (2000) documented that the soils in the oldest part of Moscow, Russia, were much richer in organic matter than those in the surrounding urban areas. Organic carbon storage in urban soils in Leicester, England, was significantly greater than

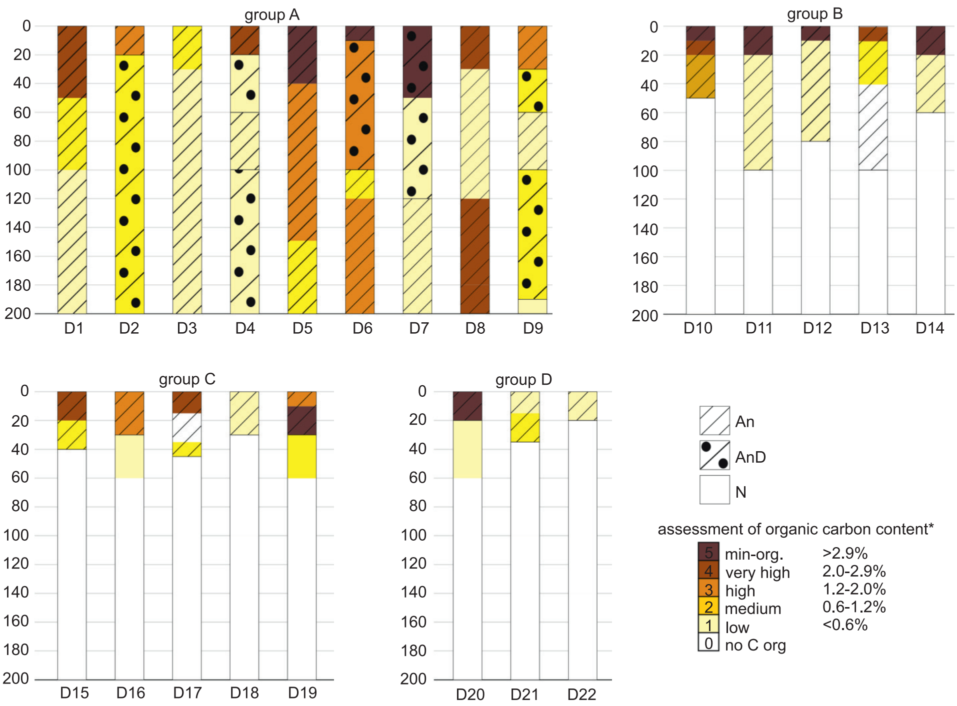

Fig. 3. Organic carbon content in tested soil groups (A-D) of the Szczecin city. See the explanation under Fig. 2. *Assessment of carbon content according to Siebielec et al. (2017)

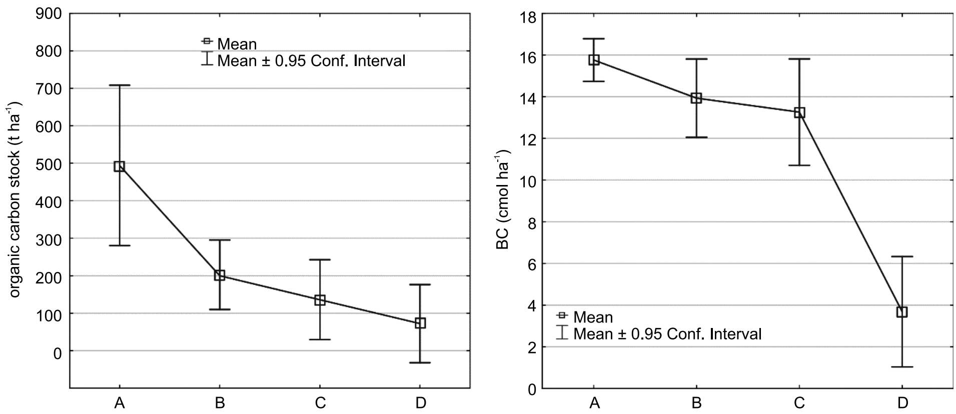

Fig. 4. Organic carbon stock and base cations (BC) in the tested soil groups (A-D) of the Szczecin city. See the explanation under Fig. 2

in regional agricultural land at equivalent soil depths (Edmondson et al. 2012). The accumulation of this ingredient in the soil profile to 100 cm resulted in total organic carbon stocks 3-5 times greater in urban soils than in natural soils (Vasenev, Kuzyakov, 2018). Analyses of soil properties in Beijing, China, suggested that the organic carbon content increased from the suburbs to the urban core (Mao et al. 2014).

Base cations

The highest base cation values were recorded in the soils of group A (average of 15.8 cmol kg^{-1}). For the soils of groups B, C, and D, the average values of this property were 13.9, 13.3, and 3.7 cmol kg^{-1}, respectively (Figure 4). The lowest base cation values in the soils of group D resulted from the fact that these soils were entirely made of sand, and anthropogenic transformations only affected their top layer. In the remaining soil groups, base cation values were clearly higher due to the presence of finer materials and the greater degree of their anthropogenic transformations, including the presence of larger amounts of artefacts.

Base cation values in urban soils are primarily shaped by the Ca content, which originates from construction debris. For this reason, the soils of group A were characterized by the highest value of this feature.

Urban soils contain substantial quantities of Ca and Mg derived from demolition activity, particularly cement and concrete (Washbourne et al. 2012). The content of potassium increased in soils from the suburbs to the urban core of Beijing, China (Mao et al. 2014).

Salinity (EC values)

EC values in the tested soils were in the ranges of 86.6-1242 μS cm^{-1} for group A, 80.1-976 μS cm^{-1} for group B, 74.7-349 μS cm^{-1} for group C, and 20.5-101.4 μS cm^{-1} for group D (Figure 5). Thus, the soils that were strongly anthropogenically transformed in the Old Town of Szczecin (group A) were characterized by the highest salinity values, whereas in the soils of group D, the values of the EC were the lowest.

The EC values increase as a result of the presence of construction debris and other anthropogenic admixtures in soils (Nehls et al. 2013, Greinert,

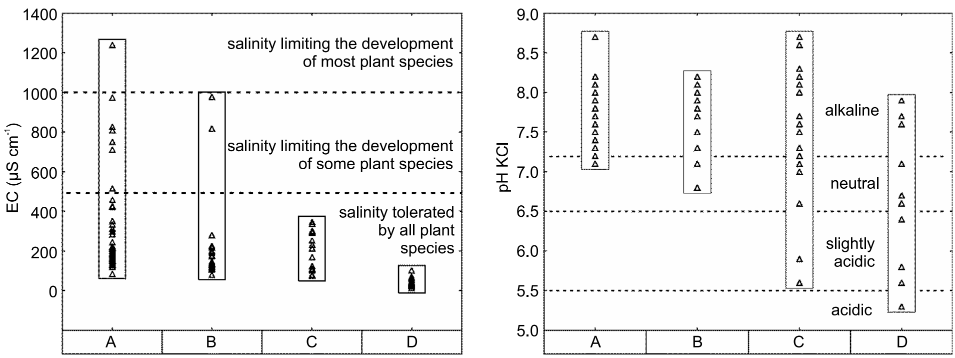

Fig. 5. Electrical conductivity (EC) and pH_{KCl} in the tested soil groups (A-D) of the Szczecin city. See the explanation under Fig. 2

Kostecki 2018). The poorly anthropogenically transformed sandy soils in the newer areas of the city of Zielona Góra, Poland, were characterized by low EC values in the range of 0-150 μS cm^{-1}. In the center of this city, in the soil layer from 0-20 cm, EC values reached 390 μS cm^{-1}, while in the deeper soil layer, within built debris materials, they reached 2500 μS cm^{-1} (Greinert 2015).

EC values below 1000 μS cm^{-1} in the entire soil profile do not limit the introduction of vegetation (Boroń et al. 2011), and EC values below 500 μS cm^{-1} are tolerated by all plant species (Lech et al. 2016).

In the strongly transformed soils of the Old Town of Szczecin (group A), an EC value above 1000 μS cm^{-1} occurred only once (in the layer from 180-200 cm), but EC values above 500 μS cm^{-1} occurred six times in these soils and two times in the soils of group B (Figure 3). This means that during planting in the Old Town area, species that can tolerate increased salinity should be considered. In the newer areas of Szczecin city, due to low salinity, all species of trees and shrubs can be introduced.

Values of pH in KCl

The pH_{KCl} values ranged from 7.1 to 8.7 for the soils of group A and from 6.8 to 8.2 for the soils of group B (Figure 3). These values indicate predominantly alkaline conditions, occasionally leaning towards neutral. Soils from the less-transformed areas of the newer areas of Szczecin city exhibited a wider range of pH_{KCl} values (group C: 5.6-8.7, group D: 5.3-7.9), signifying conditions from acidic to alkaline.

Many urban soils exhibit a high carbonate content, characteristic of construction debris, slag, ashes, and other technic materials. The presence of carbonates has an alkalizing effect, and in areas covered by Technosols, soil acidity is rarely noted due to the widespread deposition of lime-based construction waste into the soil. Soils with construction debris and a pH value below 7.0 are uncommon (Nehls et al. 2013, Greinert, Kostecki, 2018).

In natural forest soils, the pH in KCl ranges from strong acid (pH of 3.8-4.2) to alkaline (pH of 7.7-8.0) – Brożek, Zwydak (2010). However, afforestation efforts are often carried out on soils with pH_{KCl} values ranging from 7.8 to 10.8 (Pietrzykowski et al. 2011, 2018).

Heavy metal content

The maximum amounts of heavy metals were as follows: Pb – 729.0 mg kg^{-1}, Zn – 663.9 mg kg^{-1}, Hg – 5.03 mg kg^{-1}, Cd – 2.53 mg kg^{-1}, Cu – 363.7 mg kg^{-1}, Cr – 62.8 mg kg^{-1}, and Ni – 56.8 mg kg^{-1} (Figure 6).

Compared to the geochemical background values presented by Czarnowska (1996) for the soils of northern and central Poland, the maximum multiples of metal contents, considering the texture of the tested soils, were approximately as follows: Pb – 103, Cu – 91, Zn – 37, Cd – 8, Ni – 4, and Cr – 2.

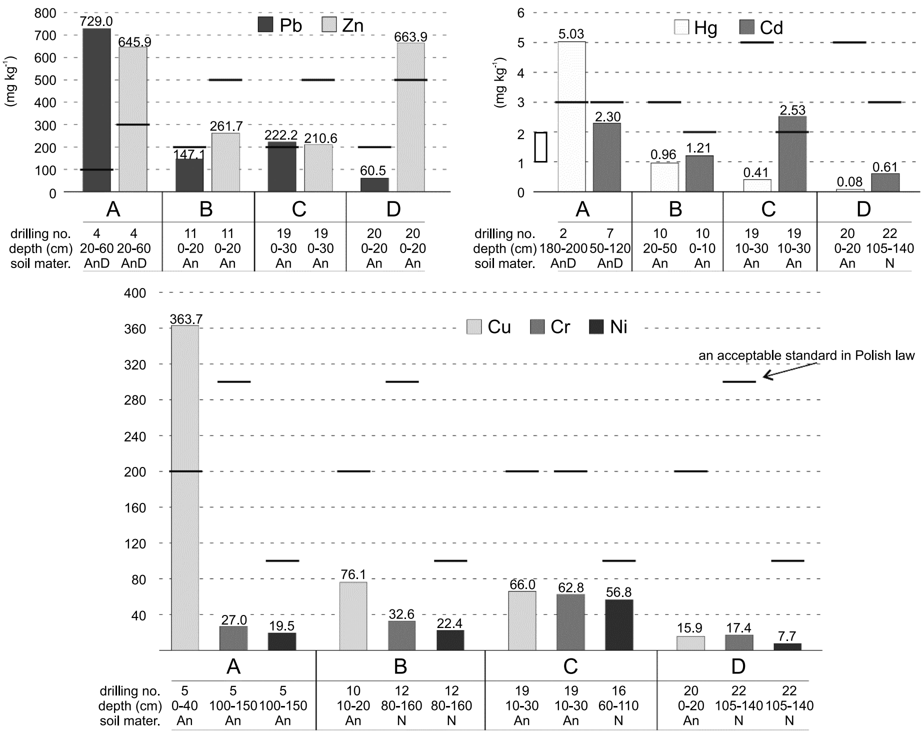

Fig. 6. Maximum contents of heavy metals in the tested soil groups (A-D) of the Szczecin city. See the explanation under Fig. 2

For Hg, the maximum multiplicity was approximately 100, assuming the natural content of this metal (geochemical background) in the Earth's continental crust (Rudnick, Gao, 2014). The highest multiplicities, in the range of 90-100, were observed for Pb, Cu, and Hg in the soils of group A.

The soils of group A from the Old Town of Szczecin were contaminated by Pb, Zn, Hg, and Cu. The contents of these metals were about twice as high as the acceptable standards in Polish law for Zn, Hg, and Cu and seven times higher than the acceptable standards in Polish law for Pb (Regulation 2016). In the area of the Old Town of Szczecin, materials contaminated by heavy metals appeared even at a depth of up to 200 cm. Values exceeding the acceptable standards in Polish law were also found in the surface layer (0-30 cm) of soils from the newer areas of Szczecin – for Pb and Cd in loamy soils (group C) and for Zn in sandy soils (group D). This situation suggests the contemporary origin of these pollutants. The Cr and Ni contents were low in all tested soils and did not exceed the values permitted by Polish law (Figure 6).

In rubble-containing subsoils of the Berlin area (Germany), the Cd, Pb, Cu, Zn, and Hg contents often exceed the precautionary values of the German Soil Conservation Act (Abel et al. 2015). Similarly, soils from Zielona Góra

(Poland), enriched with construction debris, contained maximums of approximately 603 mg Pb kg^{-1}, 454 mg Zn kg^{-1}, and 475 mg Cu kg^{-1} (Greinert 2015). In Moscow (Russia), the Cu content reached 650 mg kg^{-1} in cultural (anthropogenic) layers from the 15-16th centuries and 1910 mg kg^{-1} in brick-lime cultural layers from the 17th century (Aleksandrovskiy et al. 2015). In the cultural layers of urban Nanjing (China), the Pb content varied from 100 to more than 2000 mg kg^{-1} (Zhang et al. 2007), while in Moscow, in cultural deposits from the 19th century, it reached 1320 mg kg^{-1} (Aleksandrovskiy et al. 2015). The median values of the Pb and Zn contents specified for urban soils from 34 European cities were 102 and 130 mg kg^{-1}, respectively (Luo et al. 2012).

The scientific literature presents many examples of successful tree growth on substrates contaminated by heavy metals. The hybrid *Populus tremula* × *tremuloide* showed good survival potential, with the soil metal content reaching the following maximum levels: Ni – 290 mg kg^{-1}, Cu – 920 mg kg^{-1}, Cr – 400 mg kg^{-1}, and Cd – 29 mg kg^{-1} (Hassinen et al. 2009). Calcareous dredged sediment landfills, with metal contents ranging from 219-272 mg kg^{-1} for Cr, 45-55 mg kg^{-1} for Ni, 1145-1429 mg kg^{-1} for Zn, and 10.1-12.5 mg kg^{-1} for Cd, have been successfully afforested with *Fraxinus excelsior* L., *Quercus robur* L., and *Acer pseudoplatanus* L. (Vandecasteele et al. 2008). In Italy, mixed forests (*Picea abies*, *Abies alba*, *Fagus sylvatica*, *Ostrya carpinifolia*) have effectively overgrown polluted post-mining soils with contents of 31-96 mg kg^{-1} for Cr, 512-2494 mg kg^{-1} for Cu, 477-1338 mg kg^{-1} for Zn, and 373-7058 mg kg^{-1} for Pb (Fontana et al. 2010). Similarly, in Poland, soils in the vicinity of zinc and lead mines, which contained more than 10,000 mg Zn kg^{-1}, 900 mg Pb kg^{-1}, and Cd in the range of 57.2-80.2 mg kg^{-1}, were effectively afforested with *Populus* L., *Pinus silvestris*, and *Betula pendula* (Tarnawczyk et al. 2021).

CONCLUSIONS

The strongly anthropogenically transformed soils from the Old Town of Szczecin (group A), the earliest settled area and therefore subject to the longest urbanization pressure, were the most strongly anthropogenically transformed. These soils, classified as Urbic Technosols (Hyperartefactic), occurred within anthropogenic layers with a thickness of 200 cm, containing large amounts of technogenic admixtures, mainly construction debris. Moreover, the soils contained organic carbon throughout their entire profiles. The presence of a large number of artefacts caused their alkalization, high values of base cations, elevated salinity, and increased content of some heavy metals. The amounts of Zn, Hg, and Cu in these soils were about twice as high as the standards allowed by Polish law and Pb was about seven times higher than the standards allowed by Polish law. Metal pollution in the Old Town area occurred even up to a depth of 200 cm. The soils of the newer areas of Szczecin city, which were poorly anthropogenically transformed, contained small amounts of anthropogenic admixtures that occur to a depth of 45 cm, making them less saline and alkalized, with lower base cation values. Organic carbon was present in them up to a depth of 60 cm. These soils were contaminated with Pb, Cd, and Zn only to a depth of 30 cm, suggesting a contemporary origin of these pollutants. The species of trees tolerating increased salinity should be taken into account when new trees are planted in the Old Town area. In the newer areas of Szczecin city, due to the low salinity, all species of trees can be introduced.

Author contributions

J.Ch. – conceptualization, methodology, investigation, resources, writing; T.T. – conceptualization, methodology, writing; M.P. – software, formal analysis, visualization.

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