Review

ANTHROPOGENIC SUBSTRATES IN RELATION TO THEIR IDENTIFICATION AND CLASSIFICATION – A REVIEW

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Abstract
The paper provides an overview of the of anthropogenic substrates issue, which is an essential part of the classification and mapping of anthropogenic soils. These are related to anthropogenic processes, the variability of which is quite large. It reflects number of classification systems of anthropogenic soils, which tend to be quite different in various countries. There is a discussion of the terminology of "anthropedosphere" as an exceptional sphere of anthropogenic soils and substrates investigation, and differentiation of anthropogenic and urban soil terminology is mentioned. The soil-forming substrate is a significant part of the soil mass especially for technogenic soils. Correlation relationships between the individual systems was not yet resolved. Ten soil classification systems over the world were overviewed in relation to applied principles and criteria of anthropogenic substrates. Recognition confirms a lack of anthropogenic substrates system in most soil classification systems and their remarkable diverse used principles. The connecting element is the reference classification of WRB soils with related anthropogenic materials: artefacts, technic hard material and anthropic qualifiers. Comparing systems; several attributes were similar like presence of artifacts or human transported and altered material or human-induced properties like qualifiers Ekranic, Urbic, Spolic or Garbic. As the most elaborate systems can be considered the German Soil Classification, USDA Soil Taxonomy, and Morphogenetic Soil Classification system (MSCS). The main aim of the paper is to evaluate the system of anthropogenic substrates in the MSCS (2014) in the light of latest information in the world and to provide a new proposal for the solution of anthropogenic (also by human transported) substrates (materials) for its revised version.
Keywords: anthropogenic substrate, artefacts, soil classification system

INTRODUCTION

As the global human population and associated anthropogenic activities rapidly increase, so does the areal extent of disturbed soils. Regulatory frameworks must incorporate reclamation criteria and management options for these disturbed soils, requiring consistent descriptions and interpretations (Naeth *et al.* 2012). Many human-altered soils cannot be classified using the current concept of natural soils (Yaalon, Yaron 1966, Lehmann, Stahr 2007, Richter, Yaalon 2012, Anderson, Smith 2011, Ahrens, Engel 1999, Rossiter 2007). There is a need to mention although humans can significantly alter, transform, manipulate, and damage soil, with an incredible number of negative effects, the transformation of "natural" soils into anthropogenic soils may also have unexpected benefits (Capra *et al.* 2015, Crutzen & Steffen 2003). Currently, the development of anthropogenic soils is being studied as part of urban areas; such soils are considered to be urban soils (Burghardt 1994, Burghardt 2000, Blume, Sukopp 1976, Reinirkens 1988).

Anthropogenic mineral substrates formed during human-involved activities affecting their morphological and physical properties (depth, granularity) and thus also the hydrothermal regime of the soil

(Burghardt 2000). The exception is organogenic soils which did not originate from rocks, but from older soil material, which is mostly displaced by geomorphological processes.

The soil-forming substrate has a special position among the factors in the sense that it is, as it were, a “passive” material that is “actively” affected by external factors. Finally, it is scientifically recognized worldwide how much anthropogenic soils can deviate from natural soils (in terms of physicochemical features, pedogenic processes, matter, and energy fluxes) (Nachtergaele 2005, Lehmann, Stahr 2007, Sobocka 2000, Sobocka *et al.* 2000). Therefore, Capra *et al.* (2015) suggests definitively highlighting such differences, defining those parts of the pedosphere characterized by anthropogenic soils cover as the “anthropedosphere”.

The paper is aiming to review and recognize all significant system of anthropogenic substrates (German Soil Classification System, USDA Soil Taxonomy, Russian system of technogenic surface formations, including the WRB system, *etc.*). The reason is to find a solution and proposal for the classification of anthropogenic substrates MSCS (2014) in the light of the last knowledge in the world.

MATERIALS AND METHODS

Comparing methodology means paying attention to two or more objects to discover their relationships or to consider their differences or similarities (SAPIENS methodology). Firstly, to compare systems of anthropogenic materials or technogenic substrates to include in classification systems means to identify the systems in which these ones are present. It would be appropriate to determine the state and level of research of anthropogenic soil classification in each country and determine the similarity or dissimilarity of classification systems of anthropogenic substrates. It means to organize and connect a new concept with existing knowledge which could be utilized for new system. Thanks to the similarities and differences with others, we understand where to place it. Comparison is specifically useful for generating ideas and helps us recognize substitutes.

REVIEW

Anthropogenic processes

Anthropogenic effects, processes, objects, or materials are those that are derived from human activities, as opposed to those occurring in natural environments without human influences. (EEA 2015, Levin *et al.* 2017). The term is used in the context of environmental externalities in the form of chemical or biological wastes that are produced as by-products of otherwise purposeful human activities. For instance, it widely believed that the production of carbon dioxide is the primary factor driving anthropogenic climate change (Crutzen & Steffen 2003).

The impact of human activities on soils can examined at most spatial scales. Adderley *et al.* (2018) considers those human activities that directly influence soils, such as agricultural practices, application of waste materials and land clearance through fire husbandry. Variation in the intensity of such practices, especially contrasts between one single event and annual repetition, may lead to pronounced contrasts in the features observed between sample sites. This potentially confounds analyses and limits interpretation. By considering examples from a range of agricultural and other managed landscapes and through discussion of examples from research literature (Adderley *et al.* 2018, Kimble, Ahrens, Bryant (eds) 1998, Howard 2017) aims to the further understanding of anthropogenic features observed for soils, allowing interpretation of a range of anthropogenic processes.

Anthropogenic soils

are soils that are highly modified or constructed by human activity, with one or more natural horizons removed and replaced, added to, or significantly modified (Naeth *et al.* 2012). Disturbed horizons are anthropic in origin and contain materials significantly modified physically and/or chemically by human activities. Anthropogenic soils often display a more complex composition than natural soils. IUSS Working Group WRB (2022) reduced definition of anthropogenic soils on “soils with strong human influence”, i.e.

soils with long and intensive agricultural use, and soils containing significant amounts of artefacts. WRB 2022 describes anthropogenic soils as Anthrosols or Technosols, but the methodological approaches and classification criteria of national soil classification systems are inconsistent.

In most literary sources, there is an ambiguous understanding of anthropogenic and urban soils. Sometimes they even referred to as anthropogenic or urban soils. A clear distinction between the individual terms was recognized by Sobocká & Saksa (2022). There was proposed to distinguish two terminological terms considered as soils affected by anthropogenic factors: anthropogenic soil and urban soil. "Urban soils" can be considered as general terminology for soils occurring in urban, industrial, transport, mining, and military areas. The term "anthropogenic soils" is a "term" which could be used for soils classified according to anthropogenic diagnostic criteria and features (like anthropogenic parent materials, content of artefacts, *etc.*). It means that this classification concept could be designed only for soils classified as anthropogenic soils.

Urban soils assessment

A wide variety with strong heterogeneity in vertical direction (e.g. through soil profile) or horizontal direction (spatial differentiation) can be found within the whole city, and natural soil types contribute to the higher pedodiversity. Followed soils can be find in cities: (i) natural, semi-natural soils, (ii) partially changed soils, (iii) human-changed soils, (iv) human-made soils (artificial) soil (Sobocká *et al.* 2007). In urban areas, humans shape the surface, (re-)deposit natural or technogenic material, and thus become the dominant soil formation factor. The differentiation of the soil sites is significantly related to (i) transport and deposition, (ii) long-term deposition; (iii) mixing; (iv) sealing. (Greinert 2015, Pindral *et al.* 2020).

Permanent technogenic disturbances of urban environments and formation of technogenic sediments result in "short cycles of soils" formation and "young age" of soils of urban areas (Burghardt 2000). I.e., different susceptibility of urban soil materials to anthropogenic disturbances results in different ages of urban soils' horizons. Dust sedimentation and greenery maintenance contribute to the vertical growth of soil layers. This trend of 'topsoil' buildup is referred as "synlithogenic" trend in soil forming process (Charzyński *et al.* 2017). Synlithogenic soil formation is typical for urban soils and, in contrast, is rare for natural soils, where the major soil processes usually are directed down in the profile (except, for alluvial, colluvial and volcanic soils). In result, the relative age of urban topsoil is most often younger than of subsoil layers.

The most typical features of soil formation in described areas include (Charzyński *et al.* 2017): i) vertical growth of topsoil layers and predominantly synlithogenic soil formation process; ii) short time periods for soil formation, resulting in the early stages of pedogenesis; iii) abrupt and clear boundaries of layers and horizons, iv) specific chemical features, caused by dust deposition and anthropogenic disturbances, including alkaline pH, contamination with heavy metals and hydrocarbons, elevated carbon and phosphorous content; v) altered physical features, including high bulk density and high share of technogenic materials (artefacts) within the profile; vi) specific community of living organisms both in terms of biodiversity and total biomass.

In the past classification systems focused on natural zonal and azonal soils, whereas soils of the urban areas were absent in soil classification schemes for a long time. The lack of precise criteria for identifying soil types occurring in urban land have been appeared in many works like a description of the diagnostic horizons and soil types with the subtype subdivision fitting the principles of the new Russian soil classification (Prokofyeva, Martynenko, Ivannikov 2011) Labaz, Bogacz, Kabala (2015) describe difficulties in the classification of soils on the river terraces, extensive transformation or discussion whether soils that have undergone ore over. We suggest the inclusion of an andic subgroup in Torriarents and Torriorthents (Soil Survey Staff 1999) for anthropogenic soils presenting near-andic properties (Tejedor *et al.* 2009, Zikeli, Kastler, Jahn 2005).

Urban soil research was focused lead to human-induced alterations of heterogeneous and versatile soil types, properties, and distributional patterns in the urban environment. These attributes are often decoupled from natural soil formation factors and are highly reliant on the modifications.

Soils in urban areas, for example, often contain an elevated carbon content in the top and subsoil (Vasenev & Kuzyakov 2018, Lorenz & Shaw 2017). Total C content in urban soils was 1.5–3 times higher, and C accumulation much deeper compared with natural soils, resulting in 3–5 times larger total C stocks (Vasenev & Kuzyakov 2018). Substantial amounts of SOC, SIC, and N are sequestered in the subsoils, cultural layers, and sealed soils, underlining the importance of these hidden stocks for C assessments. We conclude that, despite the small area of cities, urban soils are hot spots of long-term soil C sequestration worldwide, and the importance of urban soils will increase in future with global urbanization.

Transformation of the soil profiles the appearance of new horizons and features, acceleration or deceleration of pedogenetic processes, is noted for the soils of botanical gardens (Chupina 2020). Differentiation of the soil properties (pH, humus content, composition of the sol adsorption complex, nutrient content, *etc.*) within a given garden is introduced plants, soil and soil management. There are many of examples of land transformation in urban environments.

Urban soils mapping

The spatial distribution pattern, however, shows no naturally occurring pattern but is particularly dependent on land use (Makki *et al.* 2019, Pindral *et al.* 2022). Sobocká *et al.* (2022) suggests mapping of pedo-urban complexes which is delineation of soil units, respecting natural or semi-natural cartographic lines, and meeting classification criteria – pedological, geomorphology, georelief. Usually there are soil types and soil associations, parent material, texture, chemical-physical properties, *etc.* Pedo-urban complex (PUC) is a geographical & cartographical unit for mapping system of abiotic, biotic and socio-economic components of the urban ecosystem in topic or choric level (large, middle or small mapping scales). Part of the pedo-urban complex can be imperviously or semi-imperviously sealed (buildings, asphalt paving, concrete, traffic networks, *etc.*). Urban ecosystem land use (industrial areas, housing estate, commercial areas, transport infrastructure, *etc.*) results in of spatial differentiation (pattern) of urban soil cover. Delineation of pedo-urban complexes respects artificial cartographic lines (land cover/land use). Specific mapping criteria are involved: land cover/land use (typical pattern), soil type (soil unit's association), soil sealing percentage (variety of Technosols), parent material (technogenic substrate thickness), soil texture, chemical properties, and risk assessment (potential) (Sobocká *et al.* 2020, Sobocká, Saksa 2022). It means that anthropogenic substrates play substantial role in typological classification of anthropogenic a technogenic soils (Hearing, Daniels, Galbraith 2005).

On a worldwide scale, the most investigated urban areas are Berlin, Osnabruck, Moscow, and New York City, as well as Bratislava (Sobocká *et al.* 2007) while several important metropolises have been partially or entirely neglected (Capra *et al.* 2015). E.g., soils in the area around Osnabrück/Northwest Germany have been strongly influenced by man. The classification of these soils based on the German and international classification systems is problematical (Meuser & Blume 2001, Blume & Giani 2005).

Anthropogenic substrates

The soil-forming substrate is a significant part of the soil mass forming from rocks, it forms the mineral stock of the soil (chemical composition) and affects its morphological and physical properties The deliberate anthropogenic movement of reworked natural and novel manufactured materials represents a novel sedimentary environment associated with mining, waste disposal, construction and urbanization.

Ford *et al.* (2014) demonstrates stratigraphical principle of anthropogenic deposits. Anthropogenic deposits display distinctive engineering and environmental properties and can be of archaeological importance. Further challenges include the designation of stratotypes, accommodating the highly diachronous nature of anthropogenic deposits and the common presence of disconformities. International lithostratigraphic guidelines would require significant modification before being effective for the classification of anthropogenic deposits. A practical alternative may be to establish an "anthrostratigraphical" approach, or "anthrostratigraphy". Anthropogenically modified ground can also offer a record of landscape evolution and the impacts of humans on the natural environment (Ford *et al.* 2014, McMillan, Powell 1999, Rosenbaum *et al.* 2003). As such, a range of approaches exist to characterize and classify artificially modified ground to inform activities including land-use planning, development and archaeological study.

A lithostratigraphic approach to classifying anthropogenic deposits could contribute to an improved understanding of the role of humans as major geological and geomorphological agents in the Anthropocene (Price *et al.* 2011). The Anthropocene, if defined, will be a chronostratigraphic unit representing a specified time interval.

The substrates systematics is an instrument for describing properties of soil types and subtypes and it is a complementation for classification of natural and anthropogenic soil (Kühn & Eberhardt 2023). There is a need to mention that in anthropogenic substrates this function is highlighted by the fact that anthropogenic (mainly technogenic) soils directly require a detailed description of anthropogenic substrates. The properties of anthropogenic substrates significantly determine the ordering of soil profiles in the corresponding classification taxon.

By using the concept of substrate, a concise and hierarchical soil solid material classification that can be used in parallel to a morphological or morphogenetic soil classification is described. It includes parent material genesis (geogenesis), fine earth texture, coarse fragments, lime and lithic carbon content, and rock type and enables to characterize the soil horizon material as a complement to the pedogenetic horizon designation and the entire soil profile as a complement to the (genetic) soil type. The system covers natural and anthropogenic substrates (as found, e.g., in urban areas, on landfills, *etc.*). Its hierarchical approach can be used in single profile descriptions, but also in soil mapping, for which it provides a framework for delineation and rule-based aggregation of spatial soil units (Kühn & Eberhardt 2023).

The process of the parent material formation (natural as geogenesis, or anthropogenic), that is, the most recent process of non-pedogenic formation or sedimentation (and its environmental setting) that distinctly affected the parent material (or, in some cases, formed the parent material, e.g., peat formation).

The substrate composition in its status, possibly already affected by pedogenesis, with

1. fine earth texture class, a class of coarse fragments size, shape and content, content of carbonates and, if present, lithogenic carbon, or
2. so-called special substrates, for which a mineral soil texture cannot be stated, on a more abstract and reduced level compared to horizon description, and the one or two most relevant components of the soil parent material. This is for unconsolidated rock coarse and fine components, or a general term for very heterogeneous material mixtures, and for consolidated rock the rock type, using geological terminology.

Additional technogenic materials that occur in urban environments can be added to the list of anthropogenic parent materials. Furthermore, authors designed appendices that clearly characterize typical soil profiles and depict technogenic materials, their physical and chemical characteristics, as well as their origin and distribution (Makki *et al.* 2019).

Anthropogenic substrates classification

Special anthropogenic substrates are in the Morphogenetic Soil Classification System of Slovakia (*Societas pedologica slovaca* 2014). Analytical data regarding soil contamination, percentage representation of artefacts, anthroskeleton, or other characteristics. Substrates in the taxonomic hierarchy are part of the description of soil units. On the Tab. 1 is shown classification of anthropogenic substrates involved in the Morphogenetic Soil Classification System of Slovakia (*Societas pedologica slovaca* 2014).

Review

Table 1
Classification of anthropogenic substrates involved in the Morphogenetic Soil Classification System of Slovakia (*Societas pedologica slovaca* 2014).

Substrates of natural origin, < 10 % artefacts (ap):	
sand	(ap1)
loam	(ap2)
clay	(ap3)
gravel	(ap4)
loamy gravel-sand	(ap5)
stony to boulder material	(ap6)
mixed loamy-gravel-sand and stony material	(ap7)
peat and humolite material	(ap8)
Substrates of natural-technogenic origin 10 – 40 % artefacts (az):	
tailings waste from the mining industry	(az1)
tailing waste from metallurgic industry	(az2)
mixed technologic-recultivation material	(az3)
Substrates technogenic Substrates > 40 % artefacts (at):	
construction waste material (with components brick, concrete, plastic material, mortar, cement, metals, glass, pitch, *etc.*)	(at1)
ashes (product of hard coal and lignite processing, combustible waste)	(at2)
slag and cinder (iron and non-ferrous metal processing waste)	(at3)
dumping waste (with household and municipal waste components)	(at4)
sludge mud (sludge waste)	(at5)
industrial waste (waste products of the chemical, metallurgical, plastic, woodworking, dyeing, gas industries)	(at6)
biotechnological waste (composted organic waste)	(at7)

Similar system also was applied in the Morphogenetic Soil Classification System of Slovakia from 2000 (VÚPOP, SPS 2000) but not well detailed. The system is prioritizing anthropogenic substrates which are predominantly formed on/from transported and transformed materials, this is the first criterion. The second differentiation criterion is the percentage of artifacts. Texture, variety, form and phases are the same like for the other soils. Soil forms are classified according to anthropogenic impacts.

According to Sobocká & Saksa (2022) two classes of anthropogenic substrates were proposed: 1. natural-technogenic origin with artifacts ≤ 20 % and the second one with ≥ 20%. This system is considered as not satisfied and needs any improvements.

The WRB (IUSS Working Group WRB 2022) separates extreme soils like Leptosols and Arenosols from other soils using threshold criteria, for which possibly a further designation of their composition applies on the second level of classification. It was done by receiving qualifiers that in turn are defined by similar single-threshold values themselves (e.g., the texture qualifiers Arenic, Siltic, Clayic, and Loamic, or the qualifier Skeletic for high mean percentages of coarse fragments down to a defined depth). E.g., special qualifiers in Technosol Reference Soil Group are in the Tab. 2. Other suggestions were presented in Dazzi & Papa (2009).

Table 2

Selected principal qualifiers in Technosols Reference Soil Group (IUSS Working Group WRB 2022) related more specifically to soils of urban and industrial areas

Qualifier	**Description**
Principal qualifier	
Ekranic	having technic hard material starting ≤ 5 cm from the soil surface
Thyric	having technic hard material starting within > 5 and ≤ 100 cm from the soil surface
Linic	having a continuous, very slowly permeable to impermeable constructed geomembrane of any thickness starting ≤ 100 cm from the soil surface
Urbic	having a layer, ≥ 20 cm thick and within 100 cm of the soil surface, with ≥ 20% (by volume, weighted average, related to the whole soil) artefacts, ≥ 35% (by volume, weighted average, related to the whole soil) of which consist of rubble and refuse of human settlements
Spolic	having a layer, ≥ 20 cm thick and within 100 cm of the soil surface, with ≥ 20% (by volume, weighted average, related to the whole soil) artefacts, ≥ 35% (by volume, weighted average, related to the whole soil) of which consist of industrial products (e.g. mine spoil, dredgings, slag, ash, rubble, *etc.*)
Garbic	having a layer, ≥ 20 cm thick and within 100 cm of the soil surface, with ≥ 20% (by volume, weighted average, related to the whole soil) artefacts, ≥ 35% (by volume, related to the whole soil) of which contain ≥ 20% organic carbon (e.g. organic waste)
Isolatic	having, above technic hard material, above a geomembrane or above a continuous layer of artefacts starting ≤ 100 cm from the soil surface, soil material containing fine earth without any contact to other soil material containing fine earth (e.g. soils on roofs or in pots)
Reductic	having reducing conditions in ≥ 25% (by volume) within 100 cm of the soil surface, caused by gaseous emissions, e.g. methane or carbon dioxide, or caused by liquid intrusions other than water, e.g. gasoline

Technic hard material

Technic hard material (from Greek *technae*, art) (IUSS Working Group WRB 2022) describes consolidated material, created or substantially modified by humans. Technic hard material: 1. is consolidated material resulting from industrial or artisanal processes; *and* 2. has properties substantially different from those of natural materials; *and* 3. is continuous or has free space covering < 5% of its horizontal extension.

In the USDA Soil Taxonomy, anthropogenic soils are classified into two basic categories depending on type of soil parent material: (1) human-altered material (HAM), and (2) human-transported material (HAM) (Galbraith & Shaw 2022) together HAHT material. These were introduced to Soil Taxonomy in 2010 and 2014 (Soil Survey Staff 2014). The differentiation includes presence on/above anthropogenic landforms (detailed description of landforms), artifacts and use of historical records. This approach is taken because of unique nature and variability of urban soils and materials. Urban soils are often low in carbon, higher pH, contain artifacts and are highly compacted and have an anthropic epipedon. Human-altered and human-transported material is at least 50 cm. Subgroups are: Anthraquic (paddy agriculture), Anthrodensic (densic contact < 100 cm deep), Anthropic epipedon, Plaggic and Haploplaggic epipedon (> 25 cm thick), Anthroportic (HTM) and Anthraltic (HAM) material > 50 cm. For the future new proposal are: Sulfuric (acid-sulphate soils) and Excavating (to unearth) (Riddle & Levin 2017, Galbraith & Shaw 2022, Bryant & Galbraith 2002). In the Tab. 3 is shown family classes with different volume of artifacts. Manufactured layers (impervious materials such a geotextile lines; asphalt or concrete layers are defined because they are root-limiting layers.

Table 3
Human altered and human transported family classes in the Soil Taxonomy (Soil Survey Staff 2014)

HA/HT family class	Description	Thickness
Methanogenic	Methane or methanethiol gas evolution	> 50 cm thick
Asphaltic	> 35% by volume Asphalt (bitumen) artifacts	> 7,5 cm thick
Concretic	> 35% by volume Concrete artifacts	> 7,5 cm thick
Gypsifactic	> 40% by volume Flue gas gypsum, phosphor-gypsum, drywall artifacts	> 7,5 cm thick
Combustic	> 35% by volume Combustion by-products (bottom ash, coal slag)	> 7,5 cm thick
Ashifactic	> 15% by volume Very light-weight combustion by-products (fly ash)	> 7,5 cm thick
Pyrocarbonic	Artifacts or pyrolysis (fuel coke, biochar)	> 7,5 cm thick
Artifactic	> 15% by volume discrete (> 2 mm) artifacts	> 50 cm thick
Pauciartifactic	15 to 35% by volume discrete (> 2 mm) artifacts	> 50 cm thick
Dredgic	Finely stratified HTM transported in water	> 50 cm thick
Spolic	HTM	
Araric	> 3% by volume detached, reoriented diagnostic material	> 7,5 cm thick

In German taxonomy normally soils and substrates are classified separately (Arbeitskreis für Bodensystematik der Deutschen Bodenkundlichegesellschaft 1998). Substrate taxonomy classifies substrates according to diagnostic substrate layers of the substrate profile and their sequences (Kühn 2007). There are numerous consolidated and unconsolidated natural rocks and artificial material and their mixtures. Comparable to soil type classification which is based on diagnostic horizons substrate classification consists of typified sequences (one or more substrate kinds and number of layers). They are 3 hierarchical level distinguished: substrate classes, types and substypes. Two main groups are: natural substrates and anthropogenic/technogenic substrates which enter to soils or deposited on existing soils or substrates. Designation of substrate composition contains following material characteristics:

i) percentage of rock fragment and artefacts fraction;
ii) content of carbonates and lithogenic carbon (e.g., from lignite and hard coal mining waste);
ii) soil texture (fine earth composition); kind of natural and artificial (technogenic) components (parent material) and their mixtures.

Frequently occurred artificially substrates are construction waste, ash, slag, mining spoil natural soil material (compost, dredged material), garbage, numerous types of sludge from industry *etc.*

As an example of settlement construction waste is illustrated in the Tab. 4 (Charzyński *et al.* 2017)

Table 4
Example of substrate kind sub-group designation: settlement construction waste

Kind of substrate: oj-nzcus (Ybz)					
substrate formation	rock fragments	carbon content class	carbonate content class	soil texture	parent material
oj	nz…	x…	c…	us	Ybz
dumped	debris grit…	coal…	carbonate…	silt sand form	settlement construction waste

Classification and Diagnostic System of Russian Soils (CSR) (Shishov *et al.* 2004) distinguished objects beyond the system as "Technogenic Surface Formation" (TSF) or non-soils. The difference, in principle concerns first the perception of soil. If in soil profile is artificial layer instead soil horizons, the body is qualified for TSF (Stroganova, Prokofyeva 2002, Prokofyeva *et al.* 2014). Several diagnostic horizons were proposed:

i) Urbic diagnostic horizon (UR) – heterogeneity considering chemical features
ii) Rehabilitation diagnostic horizon (RAT) – organic substrates of different origin ((pest, compost, fertilizers) unchanged by pedogenesis
iii) Technogenic diagnostic horizon (TCH) – technogenic deposits of different composition and origin; reworked by human activity.

Soil profiles where urban horizons (usually UR and RAT) are less than 40 cm depth and are overlaying soil horizons are identified as transitional *urbo-soils*. Soil profiles wit UR thickness more than 40 cm covering natural subsoil horizon referred to Urbanozems. Soils with RAT horizons as a result greenery or reclaiming are related to Technozems. Soils with RAT-TCH horizons are referred to Replantozems. Soils with sequence of preliminary of engineering design can consider like Constructozems Urbochemozems is a term for different horizons containing contaminant´s concentration exceeded health thresholds, diagnostic is X horizon (Prokofyeva *et al.* 2011, Charzyński *et al.* 2017).

This rather complex system is illustrated in the Table 5.

Table 5
Correspondence of technogenic surface formations with types of technogenic deposits (Prokofyeva *et al.* 2014, modified)

Types of deposit (distinguished by composition and genesis)	**Group in CSR**	**Subgroups of TSF in CSR**
Natural		
Natural occurrence	Naturfabricats	Abraliths
Technogenic		
Naturally filled	Naturfabricats	Lithostrats, Organostrats, Organolithostrats
Technogenic proper (natural substrate with inclusions of construction waste)		Lithostrats, Organostrats, Organolithostrats
Industrial (nontoxic artificial material)	Artifabricats	Artiundustrats
Recrementogenic (sewage sludge, household waste)		Artifimostrats, Artiubostrats
Dredged (anthrohydrogenic)	Naturfabricats	Lithostrats
Anthropogenic (cultural layer)	Quasizem	Urbiquasizems
Reclaimed soil-like bodies in different deposits		Technozems

In Czech Soil Classification System (Němeček *et al.* 2011) a list of soil-forming substrates is given. Among them, anthropogenic materials are also listed. They are distinguished into four groups as is shown in the Tab. 6.

Table 6
Anthropogenic substrates in the Czech Soil Classification System (Němeček *et al.* 2011

	Anthropogenic Substrates	**Characteristics**
a	from natural materials	texture, stoniness, carbonate
b	from mine spoil materials: – non-contaminated – potential contaminated	as a)
c	from landfills of industrial products: – non-contaminated – potential contaminated	texture, stoniness – coarse fragments of anthroskelet
d	garbage landfill covers: – non-contaminated – affected by CH_4 – contaminated	as a)
e	urban layered materials: – non-contaminated – organic materials – contaminated materials* – intoxic materials*	texture, stoniness – coarse fragments (bricks and others)
* risk elements, organic xenobiotics, sulphides, other toxic substances		

Between diagnostic signs of this classification can be ordered anthropogenic influence defined as more pronounced anthropogenic intervention into the soil profile, which does not destroy the structure of the soil profile and allows classification of the soil type. It refers to the soil subtype anthropic, or urbic or hortic. When such an influence is pronounced, the soil is classified as Anthroposols.

In the Hungarian Soil Classification system (Michéli *et al.* 2024) at § 8.4 Diagnostic soil materials: human-made Material/Artifact: are included: materials and substrates that have been significantly affected by human activity, which have been:

1. Artificially created or significantly modified, or
2. Extracted during human activity (e.g. mining, dredging, construction earthworks) and restored and spread on the original soil surface in other areas.

In the Slovenian Soil Classification System (Vrščaj, Grcman, Kralj 2019) technogenic material is involved and defined by following:

1. Technical material occurs in production, most often industrial processes (e.g. mine tailings, slag, electro-filter-ash, communal cleaning devices, digestates, garbage and basically not intended for growing plants).
2. Prepared soil and earth substrates with the growth of plants that occur in the production process, in which at least one of the following is added to the mixture: organic waste of various origins (compost, sawdust, bark...), mineral components (silt, loam, silty sand, clay materials, such as vermiculite, clay, perlite, limestone, etc.), composted garbage, and plant nutrients.

According to anthropogenic materials and substances several groups are distinguished:

- Construction waste (concrete, sand, brick, asphalt)
- Ash and slag
- Materials from industrial processes and industrial landfills and dumps
- Mixed waste from municipal landfills and dumps
- Anthropogenic organic substances (slurries from municipal sewage treatment plants, compost).

In the several soil classifications like Chinese (2001), Polish (2019) or French (1998) one's anthropogenic substrates absent or are tied to soil types or qualifiers.

The soil substrate as a basic soil-forming factor is absent in the current land evaluation units (BPEJ code) (Vilček *et al.* 2021). Its inclusion in the system can contribute to a better – clearer categorization of existing land units. Based on cartograms of soil-forming substrates from the time of the General Soil Survey, ten groups of substrates were defined: 0-fluvial Quaternary sediments, 1-eolian sediments, 2-neogene sediments, 3-organic sediments, 4-magmatic rocks, 5-metamorphosed rocks, 6-sedimentary calcareous rocks, 7-sedimentary flysch rocks, 8-polygenetic sediments, 9-artifacts (anthropogenic substrates). The last group consists of natural-technogenic, technogenic and anthropogenic materials created by anthropic activity, which have not been mapped so far, but are currently occurring in an increasingly large representation.

Artefacts

For components consisting of artefacts, terms are based by Burghardt (1997, 2000). Artefacts are objects >2 mm, whereas micro-artifacts are 0.25–2.0 mm, in size that were produced, modified, or transported from their source, by human activity. Artefacts are typically coal-related wastes (coal, cinders, *etc.*), waste building materials (brick, mortar, *etc.*), industrial wastes (coked coal, slag, *etc.*), and objects of archaeological significance (pottery, bone, *etc.*).

IUSS Working group WRB (2022) describes human-made, human-altered and human-excavated material. They may by physically altered (e.g. broken to pieces) but are chemically and mineralogically not or only poorly altered and still largely recognizable. Artefacts (from Latin *ars*, art, and *factus*, made) are liquid or solid substances of any size that: 1. Are one or both of the following: a. created or substantially modified by humans as part of industrial or artisanal manufacturing processes; or b. brought to the soil surface by human activity from a depth, where they were not influenced by surface processes, and deposited in an environment, where they do not commonly occur, with properties substantially different from the environment where they are placed; *and* 2. Have substantially the same chemical and mineralogical properties as when first manufactured, modified or excavated.

According to USDA-NRCS (2014) artefacts refer to materials created, modified or transported from their resource by humans usually for practical purpose in habitation, manufacturing, excavation, agriculture, or construction activities. Human artefacts recognized by US Soil Taxonomy are bitumen (asphalt), brick, cardboard, carpet, cloth, coal-combustion by-products, concrete, glass, metal paper, plastic, rubber, wood products, mechanically abraded rock fragments, and midden.

RESULTS AND DISCUSSION

It should be noted that anthropogenic substrates significantly contribute to the very characteristics of anthropogenic and, above all, technogenic soils. In the introductory part of the paper, the systems of anthropogenic substrates that have been found in several soil classification systems, or especially in scientific papers, were recognized. It should be noted that in most soil classification systems, special systems of anthropogenic substrates are not included. This fact is referring to the several reviewed soil classification systems. E.g., Polish soil classification system (Kabala *et al.* 2019) does not content the list of anthropogenic substrates although they address the classification of anthropogenic soils quite progressively. Some substrate evidence are linked to the description of anthric or hortic horizon, soils having technogenic hard layer or geomembrane, or deeply mixed heap material or soils having ≥ 20% artefacts in the upper 100 cm soil layers. Description of WRB qualifiers was utilized.

Similarly, this situation is recognized in the French soil classification (Baize & Girard (eds.). 1998) where a list of anthropogenic or technical substrate is absent. Nevertheless, anthropization activities are partially tied to the characteristics of the qualifiers. E.g. qualifier leptic describes an Anthroposol artificial or reconstitute above artificial (concrete, stone, bricks, *etc.*) or a natural hard layer.

Chinese Soil Taxonomy (CRG-CST 2001) used partly terminology of the USDA (Soil Survey Staff 1999) partly terms commonly used in the WRB. List of anthropogenic material is missing however several Anthro-epipedons can be found.

Complicated and not well-quantified system of anthropogenic substrates was involved into the Russian Soil Classification System (Prokofyeva *et al.* 2014, Gerasimova, Ananko, Savitskaya 2020, Gerasimova *et al.* 2023). This system is linked to the classification system i) natural and ii) technogenic substrates which are bind to types of technogenic surface formations (TSF). Terminology of such soil types is very specific, not commonly used, e.g. artifabricats, or quasizem, *etc.*

Another concept of anthropogenic materials was involved by USDA Soil Taxonomy (Galbraith, Shaw 2022). Principe (criterion) of human-altered material (HAM), and human-transported material is used also in the Morphogenetic Soil classification System of Slovakia (SPS 2014) except to anthropogenic landforms which is priority of the Soil Taxonomy. Description of attributes is very similar however presented like epipedon.

Czech classification system of anthropogenic substrates is presented as separate part the classification system. It consists of five groups with simple characteristics (Němeček *et al.* 2011).

Very detailed and precise system of anthropogenic substrates can be considered in the German Soil Classification System (DBG 1998). Separate list of anthropogenic material is perceived as diagnostic substrate layers of the substrate profile. Their sequences and hierarchical level distinguished: substrate classes, types and substypes with typified sequences. To use this system there is a need to be more qualified and skilled.

Selected principal and supplementary qualifiers in Anthrosols and Technosols Reference Soil Groups (IUSS Working Group WRB 2022) indirectly described specific attributes of Anthrosols and Technosols. In the separate list of diagnostic materials three of anthropogenic materials are listed: artefacts, technic hard material and colluvic (which origin is half natural, half human-induced).

Table 7 presents comparing of the 10 soil classification systems referring to existing system of anthropogenic substrate or indirect presence of anthropogenic substrate. Information is complemented by main diagnostic criteria if they exist.

Table 7

Comparison of 10 soil classification systems referring to anthropogenic substrate or indirect presence of anthropogenic substrate

Soil Classification System	Separate system of anthropogenic substrates Yes/Not	Indirect presence of anthropogenic substrate Yes/Not	Main diagnostic criteria
WRB (2022)	Yes (Artefacts, Technic hard material)	Yes (in Anthraquic, Pretic diagnostic horizons + principal qualifiers)	1. Percentage of artefacts having ≥ 20% in upper 100 cm from soil surface 2. Technic hard material starting ≤ 5 cm.
MSCS (2014)	Yes (separate system of anthropogenic substrates)	Yes (in soil subtypes, e.g., initial or recultivated)	1. Human-transported and altered material (ATM) 2 Percentage of artefacts differentiated into three groups – new classes are proposed
USDA Soil Taxonomy	Yes (HAHT Anthroportic and Anthraltic) at the family classes	Yes, at the series designation	1. HAHT material > 50 cm 2. Anthropogenic landforms 3. Artifacts 4. Use of historical records
German Soil Classification System	Yes (separate very detailed system of anthropogenic substrates)	Yes, at the soil type and soil subtype level	1. Sequences in the substrate profile 2. Percentage of rock fragments and artifacts 3. Substrate formation
Russian Soil Classification System	Yes, types of deposits tied to the specific nomenclature of TSF	Yes, urbic, rehabilitation and technogenic diagnostic horizons	1. Thickness ≥ 40 cm 2. Deposit types by composition and genesis
Czech Soil Classification System	Yes, separate group of anthropogenic substrates	Yes, partly like soil subtypes	1. Man-made substrate with heaped, mixing, recultivation, heap of waste 2. Contaminated substrates
Hungarian Soil Classification System	Yes, human-made material/artifact: materials and substrates	Yes, partly like soil subtypes	1 Artificially created or significantly modified 2. Extracted during human activity
Slovenian Soil Classification System	Yes, separate group of anthropogenic material	Yes, partly like soil subtypes	1. Technical material – products of industrial processes 2. Prepared soil-substrate material for planting
French Soil Classification System	Not	Yes, tree soil subtypes contain anthropogenic substrates description	Tied to the qualifiers related to man´s activities 1. Transformed, 2. Artificial 3. Reconstituted
Polish Soil Classification System	Not	Yes, partly like soil subtypes	Using the WRB description: anthric or hortic horizon, soils having technogenic hard layer or geomembrane, or deeply mixed heap material or soils having ≥ 20% artefacts in the upper 100 cm soil layers
Chinese Soil Taxonomy	Not	Yes, partly like epipedons	Using the USDA Soil Taxonomy and WRB terminology

Ten soil classification systems were compared in terms of addressing anthropogenic substrates. There is a need to mention that properties of anthropogenic substrates significantly determine the ordering of soil profiles in the corresponding classification taxon. The assessment concerned the presence, or rather the absence, of a separate group of anthropogenic substrates, their links to soil types or subtypes. Criteria used in the definition of anthropogenic substrates are also very important. We found that several soil classification systems do not have a separate group of anthropogenic substrates.

First, it should be noted that different concepts of soil classification systems significantly contribute to different principles of the formation of anthropogenic substrates.

There is no unified system that would uniformly classify anthropogenic materials, just as there are no uniform criteria for the classification of such substrates. The connecting link may be the World Reference Base for soils (WRB) which, however, solves this issue in a relatively simple way. The evaluation shows that the most elaborate system is the German classification system of anthropogenic substrates, separately listed types of anthropogenic substrates. Principle of the HTAH substrate from the USDA Soil Taxonomy represents other system to be recognized for anthropogenic soil classification. Slovak system of anthropogenic substrate compared to other systems seems to be more elaborate partly coinciding with the world systems.

Russian classification uses own principle and terminology which is not based on quantification limits. This system cannot be comparable to other systems as anthropogenic substrates are linked directly to technogenic surface formations. However, term "Ekranic" was introduced by Russian soil scientists (Prokofyeva *et al.* 2014).

Slovak system of anthropogenic substrate involved into the Morphogenetic Soil Classification system of Slovakia meets almost all requirement on anthropogenic substrates, accepting human transported and altered material, percentage of artefacts and differentiation of substrate materials (like dumped, reclamation, construction, industrial, *etc.*). To use USDA Soil Taxonomy in very detail described artefacts is not practicable in our conditions. The main criterion of anthropogenic material distinguishing is human transported and altered material (if it is well recognizable) accepted in the USDA Soil Taxonomy and presence of artefacts. It is separate group with quantified percentage of artefacts. Proposed system of Anthropogenic substrates to be involved into the Morphogenetic Soil Classification system of Slovakia if in the (Tab. 8). We suggest partially changed table of anthropogenic substrates in which percentage of artifacts is changed from 10 to 20%. A little vague term are substrates of natural technogenic origin (20-40%) since it is sometimes impossible to accurately determine the proportion of natural substrate with technogenic material. Into the technogenic substrates we use definition of the WRB 2022 and insert technic hard material as continuous material or has free space covering < 5%. This material will enable mapping of impermeable or semi-permeable fills in urbanized environments. The thickness of the anthropogenic material is set at ≥ 60 cm.

Table 8
Proposed system of anthropogenic substrates to be involved into the Morphogenetic Soil Classification System of Slovakia

Substrates of natural origin, < 20 % artefacts (ap):	
sand	(ap1)
loam	(ap2)
clay	(ap3)
gravel	(ap4)
loamy gravel-sand	(ap5)
stony to boulder material	(ap6)
mixed loamy-gravel-sand and stony material	(ap7)
peat and humolite material	(ap8)
Substrates of natural-technogenic origin 20 – 40 % artefacts (az):	
tailings waste from the mining industry	(az1)
tailing waste from metallurgic industry	(az2)
mixed technologic-recultivation material	(az3)
Substrates technogenic origin > 40 % artefacts (at):	
construction waste material (with components brick, concrete, plastic material, mortar, cement, metals, glass, pitch, *etc.*)	(at1)
ashes (product of hard coal and lignite processing, combustible waste)	(at2)
slag and cinder (iron and non-ferrous metal processing waste)	(at3)
dumping waste (with household and municipal waste components)	(at4)
sludge mud (sludge waste)	(at5)
industrial waste (waste products of the chemical, metallurgical, plastic, woodworking, dyeing, gas industries)	(at6)
biotechnological waste (composted organic waste)	(at7)
technic hard material (continuous or has free space covering < 5%)	(at8)

CONCLUSION

The issue of anthropogenic substrates for the classification of anthropogenic soils is being addressed for the first time in Slovakia. Ten soil classification systems were reviewed to find similar or newly discovered properties of anthropogenic materials. In particular, the criteria for their creation were discussed. These are in many cases different, as are the different classification principles of anthropogenic soils. From the point of view of the criteria, the most important element of diagnosis are artifacts and material properties resulting from past use. The transported materials are diagnostic for the USDA Soil Taxonomy and for the Slovak classification scheme of anthropogenic materials also.

Given that there is no unified system for the diagnosis and classification of anthropogenic substrates, it is desirable to continue research, especially in the context of international projects.

REFERENCES

Adderley, W.P., Wilson, C.A., Simpson, I.A, Davidson D.A. (2018). Anthropogenic Features (chapter 26). In*: Interpretation of Micromorphological Features of Soils and Regoliths (2nd Edition)*, 2018, p. 753–777. DOI: https://doi.org/10.1016/B978-0-444-63522-8.00026-7.

Ahrens, R.J., Engel, R.J. (1999). Soil taxonomy and anthropogenic soils. In *Proceedings of the Classification, Correlation and Management of Anthropogenic Soils Workshop.* Eds by Kimble, J.M., Ahrens, R.J, Bryant, R.B. National Soil Survey Centre, Lincoln, NE. p. 7–11.

Anderson, D.W., Smith, C.A.S. (2011). A history of soil classification and soil survey in Canada: personal perspectives. *Can. J. Soil Sci.*, vol. 91(5): 675–694.

Arbeitskreis für Bodensystematik der Deutschen Bodenkundlichegesellschaft (1998). Systematik der Böden und der bodenbildenden Substrate Deutschlands, 2nd *Mitteilungen der Deutschen Bodenkundlichen Gesellschaft*, Vol. 86. DBG.

Baize, D., Girard, M.C. (eds.). 1998. *A sound reference base for soils: the 'referentiel pedologique'.* Institut National de la Recherche Agronomique (French National Institute for Agricultural Research), Paris, France. 328p. ISBN 2-73800811-9.

Blume, H.P., Giani, L. (2005). Classification of soils in urban/industrial agglomerations in Germany and recommendations for the WRB. *Eurasian Soil Sci*., vol. 38: 72–74.

Blume, H.P., Sukopp, H. (1976). *Okologische Bedeutung anthropogener Bodenveranderungen (Ecological significance of anthropogenic soil changes).* Schriftenreihe f. Vegetat. 10, Bonn-Bad Godesberg. pp. 75–89.

Bryant, R.B., Galbraith, J.M. (2002). Incorporating anthropogenic processes in soil classification. In *Soil classification: A global desk reference.* Edited by H. Eswaran, R.J. Ahrens, T.J. Rice, B.A. Stewart. CRC Press, Boca Raton, FL. pp. 57–66.

Burghardt, W. (1994). Soil in urban and industrial environments. *Z. Pflanzenernahr. Bodenkd*. vol. 157: 205–214.

Burghardt, W. (1997). Soil mapping instruction for urban and industrial site – Characterization of substrates by layers und mixtures. *International conference problems of anthropogenic soil formation*. Symposium conducted at the meeting of V.V. Dokuchaev Soil Institute, Moscow

Burghardt, W. (2000). The German double track concept of classifying soils by their substrate and their anthropo-natural genesis: The adaptation to urban areas. In: W. Burghardt & C. Dornauf (Eds.), *First international conference on soils of urban, industrial, traffic and mining areas* (p. 205). University of Essen.

Capra, G.F., Ganga, A., Grilli, E., Vacca S., Buondonno, A. (2015). A review on anthropogenic soils from a worldwide perspective. *J. Soils Sediments,* vol. 15: 1602–1618, doi.org/10.1007/s11368-015-1110-x.

VÚPOP, SPS (2000). *Morfogenetický klasifikačný systém pôd Slovenska. Bazálna referenčná taxonómia.* (Morphogenetic soil classification system of Slovakia. A basic reference system). VÚPOP, Bratislava. 76p. ISBN 80-85361-70-1.

Cooperative Research Group of Chinese Soil Taxonomy (CRG-CST). (2001). *Chinese Soil Taxonomy.* Science press, Beijing, New York. 203p. ISBN 7-03-008852-2.

Crutzen, P.J., Steffen, W. (2003). How long have we been in the Anthropocene era? *Climatic Change,* vol. 61(3): 251–257.

Charzyński, P., Galbraith, M.J., Kabała, C., Kuhn, D., Prokofeva, T.V., Vasenev, V. (2017). Classification of urban soils. In: Levin, M.J., Kye-Hoon J.K., Morel J.-L., Burghardt W., Charzynski, P., Shaw R.K. (eds.) (2017). *Soils within cities.* Catena-Schweizerbart, Stuttgart. ISBN 978-3-510-65411-6.

Chupina, V.I. (2020). Anthropogenic Soils of Botanical Gardens: A Review. *Eurasian Soil Science,* vol. 53(4): 523–533. DOI: 10.1134/S1064229320040043.

Dazzi, C., Papa G.L., Palermo, V. (2009). Proposal for a new diagnostic horizon for WRB anthrosols. *Geoderma*, vol. 151: 16–21.

EEA (2015). *Anthropogenic processes.* Available on the website: https://www.eea.europa.eu/themes/water/glossary/anthropogenic-processes.

Ford, J.R., Price, S.J., Cooper, A.H., Waters C.N. (2014). *An assessment of lithostratigraphy for anthropogenic deposits.* Geological Society London Special publication. https://doi.org/10.1144/SP395.

Galbraith, J., Shaw, R.S. (2022). *Human-altered and human-transported soils.* Available on https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcseprd1343023.

Gerasimova, M.I., Stroganova, M.H., Možarova, H.V., Prokofyeva, T.V. 2023. *Antropogennye počvy: genesis, geografija, rekultivacija, Učebnoje posobije.* Pod redakciej akademika RAN G.B. Dobrovoľskogo, Smolensk: Ojkumena, 2023, 268 s. ISBN 5-93520-039-2.

Gerasimova, M.I., Ananko, T.V., Savitskaya, N.V. (2020). Approaches to the introduction of human-modified soils in the updated version of the soil map of Russia, 1:2.5 m scale (by example of Moscow oblast). *Eurasian Soil Sci*., vol. 53: 16–26.

Greinert, A. (2015). The heterogeneity of urban soils in the light of their properties. *J Soils Sediments,* vol. 15: 1725–1737 (2015). https://doi.org/10.1007/s11368-014-1054-6.

Hearing, K.C., Daniels, W.L., Galbraith, J.M. (2005). Mapping and classification of southwest Virginia mine soils. *Soil Sci. Soc. Am. J*., vol. 69: 463–472.

Howard, J. (2017). *Anthropogenic Soils. Progress in Science.* Springer Cham. ISBN: 978-3-319-54330-7. DOI: https://doi.org/10.1007/978-3-319-54331-4.

IUSS Working Group WRB. (2015). *World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps*. FAO. https://www.fao.org/3/i3794en/I3794en.pdf

IUSS Working Group WRB. (2022). *World reference base for soil resources: International soil classification system for naming soils and creating legends for soil maps* (4th ed.). International Union of Soil Sciences (IUSS).

Kabała, C., Charzyński, P., Chodorowski, J., Drewnik, M., Glina, B., Greinert, A., Hulisz, P., Jankowski, M., Jonczak, J., Łabaz, B., Łachacz, A., Marzec, M., Mendyk, Ł., Musiał, P., Musielok, Ł., Smreczak, B., Sowiński, P., Świtoniak, M., Uzarowicz, Ł., Waroszewski, J. (2019). Polish soil classification, 6th edition – Principles, classification scheme and correlations. *Soil Science Annual*, vol. 70(2): 71–97.

Kimble, J.M., Ahrens, R.J, Bryant, R.B. (eds) 1988. *Classification, Correlation and Management of Anthropogenic Soils.* Proceedings of the Workshop. National Soil Survey Centre, Lincoln, NE.

Kühn, D. (2007). Praktische Probleme der Klassifikation und Kartierung von anthropogenen Substraten. *Mitt. Dt. Bodenkdl.* Ges.110(2): 499-500.

Kühn, D., Eberhardt, E. (2023). A classification of soil solid material for natural and anthropogenic soils. *Journal of Plant Nutrition and Soil Science*, vol. 186: 507–521. https://doi.org/10.1002/jpln.202200444.

Labaz, B., Bogacz, A., Kabala, C. (2015). Anthropogenic transformation of soils in the Barycz valley-conclusions for soil classification/Antropogeniczne przeksztalcenia gleb w Dolinie Baryczy-wnioski dotyczace klasyfikacji gleb." *Soil Science Annual* 65.3 (2014): 103. DOI: 10.1515/ssa-2015-0001.

Levin, M.J., Kim, K.-H.J., Morel J.L., Burghardt W, Charzynski, P., Shaw, R.K. (eds on behalf of IUSS Working Group SUITMA) 2017. *Soils within Cities*. CATENA-Schweizerbart, soil sciences, Stuttgart. ISBN 978-3-510-65411-6.

Lehmann, A. (2006). Technosols and other proposals on urban soils for the WRB (World reference base for soil resources). *Int. Agrophysics*, vol. 20: 129–134.

Lehmann, A., Stahr, K. (2007). Nature and significance of anthropogenic urban soils. *J. Soils Sediments*, vol. 7: 247–260.

Makki, M., Thestorf, K., Hilbert, S., Thelemann, M., Makowski, L. (2019). Guideline for the description of soils in the Berlin metropolitan area: an extension for surveying and mapping anthropogenic and natural soils in urban environments within the German soil classification system. *J Soils Sediments* 21, 1998–2012. https://doi.org/10.1007/s11368-020-02832-8.

McMillan, A.A., Powell, J.H. (1999). *BGS rock classification scheme volume 4: Classification of artificial (man-made) ground and natural superficial deposits – applications to geological map and datasets in the UK.* British Geological Survey, Nottingham, UK.

Meuser, H., Blume, H.P. (2001). Characteristics and classification of anthropogenic soils in Osnabruck area, Germany. *J. Plant Nutr. Soil Sci*., vol. 164: 351–358.

Michéli Erika, Fuchs Márta, Láng Vince, Csorba Ádám, Dobos Endre, Szegi Tamás, Kele Gabriella (2024). *A diagnosztikus szemléletű hazai talajosztályozási rendszer.* Útmutató. Második közelítés. Magyar Agrár- és Élettudományi Egyetem, Gödöllő., 51p. Available on the website: https://m2.mtmt.hu/gui2/?mode=browse&params=publication;35615608.

Nachtergaele, F. (2005). The "soils" to be classified in the World Reference Base for Soil Resources. *Eurasian Soil Sci*., vol. 38: 13–19.

Němeček, J., Mühlhanselová, M., Macků, J., Vokoun, J., Vavříček, D. Novák, P. (2011). *Taxonomický klasifikační system půd České republiky.* 2. upravené vydání. ČZU Praha, 94p. ISBN 978-80-213-2155-78

Murphy, M.A., Amos Salvador, A. 1999. *International Subcommission on Stratigraphic Classification of IUGS International Commission on Stratigraphy International Stratigraphic Guide* — An abridged version https://www.idigbio.org/wiki/images/7/7f/255-271_Murphy_.pdf.

Naeth, M.A., Archibald, H.A., Nemirsky, C.L., Leskiw, L.A., Brierley, J.A., Bock, M.D., *et al.* (2012). Proposed classification for human modified soils in Canada: anthroposolic order. *Can. J. Soil Sci*., vol. 92: 7–18.

Pindral, S., Kot, R., Hulisz, P., Charzyński, P. (2020). Landscape metrics as a tool for analysis of urban pedodiversity. *Land Degradation & Development,* 31, 2281-2294. DOI: https://doi.org/10.1002/ldr.3601.

Price S. J., Ford J. R., Cooper A. H. & Neal C. (2011). Humans as major geological and geomorphological agents in the Anthropocene: the significance of artificial ground in Great Britain. In: Zalasiewicz, J. A., Williams M., Haywood A. & Ellis M. (eds.) *The Anthropocene: A New Epoch of Geological Time. Philosophical Transactions of the Royal Society (Series A)*, 369,1056–1084.

Prokofyeva, T.V., Martynenko, I.A., Ivannikov, F.A. (2011). Classification of Moscow soils -and parent materials and its possible inclusion in the classification system of Russian soils. *Eurasian Soil Sc.* 44, 561–571 (2011). https://doi.org/10.1134/S1064229311050127.

Prokofyeva, T.V., Gerasimova, M.I., Bezuglova, O.S., Bakhmatova, K.A., Goljeva, A.A., Gorbov, S.N., Zharikova, E.A., Matinyan, N.N., Nakvasina, E.N., Sivtseva, N.E. (2014). Inclusion of soils and soil-like bodies of urban territories into the Russian soil classification system. *Eurasian Soil science*, vol. 47: 959-967.

Reinirkens, P. (1988). Urbane boden: ein anwendungsorientierter stadtökologischer klassifikationsversuch (Urban land: an application-oriented classification attempt). *Mitteilgn. Dtsch. Bodenkundl. Ges.,* vol. 56: 393–398.

Riddle, R.I., Levin M.J. (2017. Anthropogenic soil criteria, identification and classification of human altered and human transported materials. In: Levin, M.J., Kye-Hoon J.K., Morel J.-L. Burghardt W., Charzynski P., Shaw R.K. (eds) (2017). *Soils within cities.* Catena-Schweizerbart, Stuttgart. ISBN 978-3-510-65411-6.

Richter, D.D., Yaalon, D.H. (2012). The changing model of soil revisited. *Soil Sci. Soc. Am. J.,* vol. 76(3): 766–778.

Rosenbaum, M.S., McMillan, A.A., Powell, J.H., Cooper, A.H., Culshaw, M.G., Northmore, K.J. (2003). Classification of artificial (man-made) ground. *Eng. Geol.,* vol. 69: 399–409.

Rossiter, D.G. (2007). Classification of urban and industrial soils in the World Reference Base for Soil Resources. *J. Soils Sediments,* vol. 7: 96–100.

SAPIENS methodology. Available on https://metodologiasapiens.com/en/metodos/mas-informacion-metodo-comparativo/

Shishov, L.L., Tonkonogov, B.D., Lebedeva, I.I., Gerasimova, M.I. (2004). *Klassifikacija I diagnostika počv Rossii.* Smolensk: Ojkumena, 2004, 342s. ISBN 5-93520-044-9.

Sobocká, J. (2000). Position of Technosols in the Slovak soil classification system and their correlation. *Gruntoznalstvo*, (Pedology), vol. 9: 177–182.

Sobocká, J. *et al.* (2007). *Urbánne pôdy (príklad Bratislavy).* (Urban soils (a case study of Bratislava). Monografia VÚPOP Bratislava, 126 + príloha (CD). VÚPOP Bratislava, ISBN 978-8089128-39-6.

Sobocká, J., Saksa, M., Feranec, J., Szatmári, D., Kopecká, M. (2020). A complexity related to mapping and classification of urban soils (a case study of Bratislava city, Slovakia). *Soil Science Annual,* doi:10.37501/soilsa/127525. Dostupné na internete http://www.soilsa.com/A-complexity-related-to-mapping-and-classification-of-urban-soils-a-case-study-of,127525,0,2.html

Sobocká, J., Saksa, M. (2022). Reassessment of the anthropogenic soil classification in the light of the newest knowledge. *Pedosphere Research*, vol. 2 no.1, pp. 35-47. NPPC – VÚPOP. ISSN 2729-87-28.

Societas pedologica slovaca. 2014. *Morfogenetický klasifikačný systém pôd Slovenska. Bazálna referenčná* *taxonómie.* Druhé upravené vydanie, (Morphogenetic classification system of soils of Slovakia. Basal reference taxonomy. Second revised edition). Bratislava, NPPC-VÚPOP, 96p. ISBN 978-80-8163-005-7.

Soil Survey Staff (1999). *Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys* (2nd ed.) Agriculture Handbook: Number 436. USDA. https://www.nrcs.usda.gov/sites/default/files/2022-06/Soil%20Taxonomy.pdf.

Soil Survey Staff. (2014) *Keys to Soil Taxonomy.* 12th Edition, USDA-Natural Resources Conservation Service, Washington DC.

Strain, M.R., Evans, C.V. (1994). Map unit development for sand and gravel pit soils in New Hampshire. *Soil Sci. Soc. Am. J.,* vol. 58: 181–185.

Stroganova, M., Prokofyeva T. (2002). Urban soils classification for Russian cities of the taiga zone. *In* Proceedings of the 2001 *International Symposium on "Soil Classification"*. Edited by E. Micheli, F.O. Nachtergaele, R.J.A. Jones, L. Montanarella. European Communities, Luxembourg. pp. 153–156.

Tejedor, M., Jimenez, C., Armas-Espinel, S., Hernandez-Moreno, J.M. (2009). Classification of anthropogenic soils with andic properties. *Soil Sci. Soc. Am. J.* vol. 73: 170–175.

Vasenev, V., Kuzyakov, Y. (2018). Urban soils as hot spots of anthropogenic carbon accumulation: Review of stocks, mechanisms and driving factors. *Land Degradation and Development* 29(6), DOI: 10.1002/ldr.2944.

Vilček, J., Koco, Š., Takáč, J., Bezák, P., Ilavská, B. (2021). *Sú ešte bonitované pôdno-ekologické jednotky aktuálne?* (Are the land evaluated soil-ecological units still up to date?) https://www.agroporadenstvo.sk/nove-poznatky-poda?article=2108.

Vrščaj, B., Grcman, H., Kralj, T. (2019). *Klasifikacija tal Slovenije 2019. Sistem za opisovanje in poimenovanje tal Slovenije.* Available on the website : https://www.gov.si/assets/ministrstva/MOPE/Okolje/Tla/Klasifikacija_tal_Slovenije.pdf.

VÚPOP, SPS. (2000). *Morfogenetický klasifikačný systém pôd Slovenska. Bazálna referenčná taxonómia*. (Morphogenetic classification system of soils of Slovakia. Basal reference taxonomy). Výskumný ústav pôdoznalectva a ochrany pôdy, Bratislava, 76p. ISBN 80-85361-70-1.

Yaalon, O.H., Yaron, B. (1966). Framework for manmade soil changes: outline of metapedogenesis. *Soil Sci*., vol. 102: 272–277.

Zikeli S., Kastler M., Jahn, R. 2005. Classification of anthrosols with vitric/andic properties derived from lignite ash. *Geoderma*, vol. 124: 253–265.