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PEDO-CHEMICAL AND BIOLOGICAL CHARACTERISTICS OF URBAN SOILS

SUMMARY

of PhD Thesis

for the conferment of the educational and scientific degree of PhD,
in the scientific specialty "Soil Science."

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The PhD thesis consists of 131 pages and comprises 10 chapters, organized as follows: Introduction, Research Objectives, Literature Review, Study Subjects, Research Methods, Results and Discussion, Conclusions, Scientific and Scientific-Practical Contributions, Literature (233 references), and Publications related to the Dissertation (3 in total). Within the text, you can find 46 figures and 31 tables. The research objectives are outlined in six points. This literature review spans 19 pages and covers contemporary sources related to the topic of this dissertation. The study subjects included soils from eight zones, situated according to the urbanization gradient, from northwest to southeast in the Sofia Metropolitan Municipality, in previously unexplored soil areas. Detailed descriptions of field research methods, sample collection, and physical, physicochemical, chemical, biological, radioisotopic research methods, and statistical methods for analyzing the obtained data are provided. The Results and Discussion section delves into the genetic and classification characteristics of the studied soils, soil formation conditions, and the chemical, physicochemical, radioisotopic, and biological features of the soils under investigation. The conclusions and scientific and practical contributions of this study are summarized in three pages. The table and figure numbering in the summary correspond to this PhD thesis.

The date, time, and location of the public defense

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I. Introduction

Studies of soils in urban areas have revealed a vast diversity of geological, petrographic, geographical, paleontological, geochemical, physicochemical, and biological characteristics that impart them with specific profiles and qualities. This diversity necessitates a detailed examination of the composition, structure, and properties of these soils as well as an assessment of the degree of anthropogenic influences on them and their consequences for the environment. Living conditions in urban environments are of utmost importance because cities concentrate on the majority of the population, industry, and economy. Today, cities represent a unique combination of ethnic, aesthetic, production, trade, social, and tourist symbols, intertwined with landscape and ecological features.

Urban soils are formed and developed with varying degrees and types of anthropogenic influence. Given their role as factors that determine the quality of human life, it is important to study their properties. Periodic monitoring of soil indicator parameters provides information about the dynamics of their changes under the influence of various natural and anthropogenic factors, and serves as a basis for assessing the ecological functions of soils. A significant scientific interest lies in clarifying the different aspects of the interaction between parameters of the geochemical environment (potentially and readily available chemical elements, pH, ion exchange capacity, redox potential) and the enzymatic activity of anthropogenically impacted soils, including their sensitivity and vulnerability to different chemical environments, element biomigration, chemical speciation, and others. These processes have not been adequately explored in urban zone soils.

II. Research Objectives

The main scientific objectives that will be addressed in this dissertation are: a) determining the contemporary morpho-genetic characteristics of soils in urban areas influenced to varying degrees by urbanization; b) classifying the studied soils; c) assessing the chemical and geochemical characteristics of the soils; d) establishing the content of α-, β-, and γ-emitting radionuclides in the soils and evaluating the radioactive burden in the urban environment; e) determining the microbiological and enzymatic activity of the studied soils; and f) assessing the ongoing changes in urbanized soils.

III. Literature Review

Today, we are witnessing excessive population growth, with over half of the population residing in urbanized areas, a percentage that is expected to increase in the future. The management of soil resources in cities is largely dominated by housing construction, which unfortunately views soils as a foundation for construction, often referring to them as 'construction' soils. Just over 40 years ago, the condition of urban soils received little attention from scientists and society. Some of these soils have undergone significant structural and compositional changes that now fall into the category of technogenic soils. They contain large amounts of toxic materials produced by humans. All of these factors have a negative impact on their properties, structure, and fertility.

Many attempts have been made to describe and classify these soils, but they exhibit significant vertical and horizontal spatial diversity. Craul (1985) formulated eight criteria for identifying these soils. Rapid urbanization during the 20th century led to a substantial increase in soils with altered purposes, which, depending on where they were formed, exhibit a wide variety of characteristics, features, properties, and processes. In our country, nearly 0.5 million hectares have been subjected to anthropogenic impacts, with a significant portion of our industrial giants from the recent past built on fertile lands previously used mainly for growing vegetables and field crops.

The first attempt to study urban soils in Western Europe and create an urban soil map was carried out by Mückenhausen and Müller (1951), who mapped a part of Bottrop, Germany, which was heavily damaged during World War II. In Poland, Skawina researched soil-forming processes in mounds created by the coal industry, whereas in 1981, Blume and Schlichting organized an international symposium on urban soils in Berlin, Germany. This was the first successful attempt to gather scientists studying urban soils. In Bulgaria, Gencheva actively worked on the classification of these soils during the 1970s, the 1980s, and the 1990s. In 1988, the FAO World Soil Legend, known as the World Soil Classification, included these soils as anthrosols and categorized them as soils in which human activities led to deep modification or burial of the original soil horizons through the removal or disruption of surface horizons, cuttings and fillings, additions of organic materials, and continuous irrigation. In 1998, the Working Group "Soils of Urban, Industrial, Traffic, and Mining Areas" (SUITMA) was established. The first international conference on these issues took place in Essen, Germany in 2000, followed by conferences in Nancy (France, 2003), Cairo (Egypt, 2005), and Nanjing (China, 2007), which significantly contributed to the development of the subject. Since 2006, in the World Soil Reference Base for Soil Resources, anthropogenic soils have been divided into two soil reference groups: Technosols, which contain significant artifacts, with "properties and pedogenesis determined by their technogenic origin," and Athrosols, soils influenced by intensive and continuous agriculture.

As a key component of urban ecosystems, urban soils accumulate and retain heavy metals through soil adsorption for extended periods. Sources of heavy metals in urban conditions include automobile traffic, industrial activities, corrosion of building structures or materials, and coal combustion in power plants. In addition to heavy metals, some soils contain elevated levels of organic pollutants including polycyclic aromatic hydrocarbons, pesticides, biocides, and pharmaceuticals.

However, pollution is not the only characteristic of urban soils. They are often highly compacted, fragmented by large amounts of construction waste, and poorly enriched with humus and nutrients, rendering them unsuitable for creating effective green systems. These soils are important for regulating the water cycle (urban hydrology and infiltration), transporting and absorbing pollutants, controlling air quality (fine particulate matter and pollutants), and mitigating the local climatic effect of the heat island.

As a product of rock weathering, soils inherit their mineral composition and contain trace amounts of natural radioactive elements (Naydenov and Zaharinov, 2012). potassium-40, uranium-238, thorium-^{232}, and radium-226 are the primary natural radioactive elements in soil. The potassium content in soils, aside from rock sources, can also be influenced by human activities, such as the use of potassium fertilizers, cultivation of potassium-loving plants, and land improvements. However, the significance of other rare radioactive elements remains limited.

Primarily, knowledge of the radioactive elements present in soil supplements our understanding of the geochemical composition of the soil and its characteristics as a natural entity. The relationships between radioactive elements and their daughter products help to elucidate certain processes in the soil, the progression of weathering processes, and soil formation.

Changes in the physical and chemical properties of urban soils can also influence their biological characteristics. Urbanized soils can be subjected to various natural or human-induced factors. Their stability depends largely on the soil biota, with microorganisms playing crucial roles. Soil microflora is known for its role in the transformation of organic substances in the soil, cycling of biogenic elements, and formation of soil structures. The interactions between soil microorganisms and plants are fundamental to terrestrial ecosystems. Soil microorganisms possess significant ecological plasticity, meaning that they can adapt to changes in the soil environment. Through their biochemical activities, they can contribute to soil remediation by breaking down toxic substances; however, they can also inhibit their development depending on the form and concentration of pollutants. Therefore, parameters characterizing the abundance and activity of soil microflora can be used as early indicators of disturbances in the ecological balance of soil. In international scientific literature, there are numerous publications on the biological properties of soils in urbanized areas. Zhao et al. (2013) reported a decrease in the total microbial biomass accompanied by an increase in the functional diversity of soil microorganisms in urban soils in Beijing, China. Dec (2014) noted a reduction in dehydrogenase and phosphatase activities in urban soils located near roadways. According to Cousins et al. (2003), the species diversity and spore abundance of mycorrhizal fungi in urban soils are lower than those in agricultural soils of the same type. Zhao et al. (2013) found that different land-use practices in urban soils indirectly affect the quantity of soil microbial biomass. Gorbov et al. (2014) established a clear relationship between organic matter content and enzymatic activity in anthropogenically altered soils - high enzymatic activity is typical for horizons with a maximum amount of organic matter. Data from Gorbov et al. (2014) showed that catalase, invertase, and polyphenol oxidase activities in urban conditions are significantly lower in carbonated chernozem soils than in their natural counterparts. There are also publications (Machulla, 2000; Xu et al., 2014) where no negative changes in the microbiological activity of soil microflora in urban areas were observed. Clearly, specific locations and land-use practices play a crucial role in the biological properties of urban soils. In our country, soils from urban areas have been insufficiently studied from a microbiological perspective.

Studies and projects have demonstrated the possibility of making urban development more environmentally friendly. To achieve this, strategies need to be developed to address the "source problems" (exhaustion, pollution, disruption) and the "site pollution problems" (pollution, disruption) caused by cities. Science plays a fundamental role in finding ways to enhance the capacity of urban ecosystems as well as in their establishment, improvement, and preservation for future generations. Insufficient scientific information about urban soils and their significance for the urban population environment necessitates the establishment of geomorphological, pedogenic, and geochemical characteristics as key factors in their modern evolution.

IV. Research objects

The selection of research sites to track the impacts on soils in an urban environment is based on the urbanization gradient and typology of urban ecosystems in Bulgaria. Soils located in green areas of residential complexes, suburban areas, and those near the road network were chosen for the study (Figure 5). To investigate the population density factor, a profile in an area with lower residential density was selected (Figure 6).

Figure 5. Aerial view of Sofia City and location of the studied pedons.

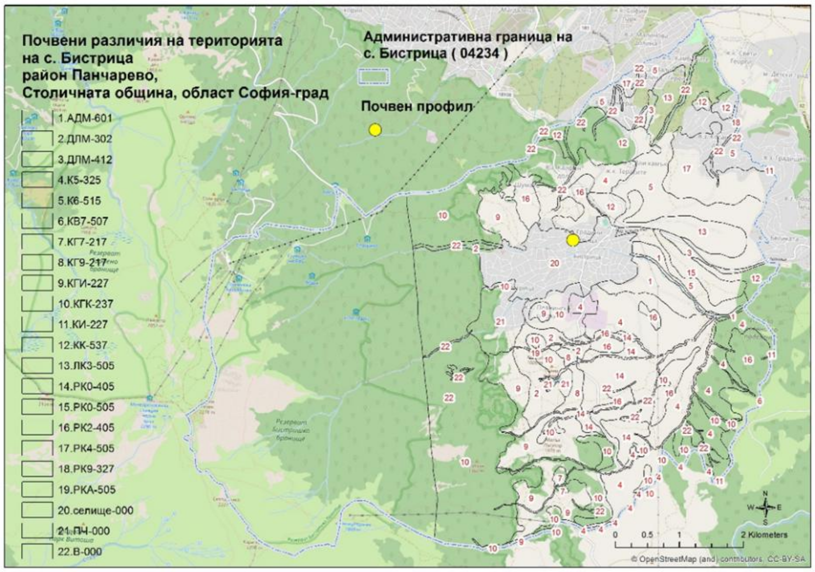


Figure 6. Soil map of Bistritsa village and location of the soil profile.

IV. 1. Location of the Studied Soils in the Urban Area of Sofia City

Profile 1 is situated in the center of an interblock area in the Mladost 1 micro-district, opposite The Mall Tsarigradsko Shose, with geographical coordinates: N 42° 39.449'; E 023° 72.811'.

Profile 2 is located in the Mladost 1A micro-district, 100 m from the Mladost 3 metro station, with geographical coordinates: N 42° 38.762'; E 023° 23.144'.

Profile 4 is positioned in an undeveloped area within the Druzhba 2 residential complex, 20 m east of the Sofia East Thermal Power Plant (TPP Sofia East) and 500 m from the western bank of the Iskar River. Its geographical coordinates are N 42° 39.074' and E 023° 24.794'.

Profile 5 is situated in a peri-block area of the Druzhba 2 residential complex, 150 m from the western bank of the Iskar River, with geographical coordinates: 42° 38.418 ‘E 023° 25.022’ E.

Profile 6 characterizes a peri-block area of the Mladost 1 micro-district, located 5 m from Alexander Malinov Boulevard, with the geographical coordinates: N 42° 38.418'; E 023° 25.022'.

Profile 7 and Trench 2 are located in a microdepression on the banqueted section of the Shose Bankya Street. The profile has the following geographical coordinates: N 42° 71.918' and E 023° 72.808'. The trench was situated 10 m southwest of the profile.

IV. 2. Location of the Studied Soils in the Suburban Area of Sofia City

Profile 3 is positioned 200 m south of the ring road in an undisturbed area with a slight northward slope, with geographical coordinates of 42° 37.313 ‘E 023° 23.107’ E. Trench 1 is 4 meters south of the ring road, on the periphery of a gently sloping area, with geographical coordinates: N 42° 37.221'; E 023° 23.764'.

IV. 3. Location of the studied soils in the low-density residential area (Bistritsa village).

Profile 8 is located in a private yard on the northeastern outskirts of Bistritsa village on a western slope with a slight southward inclination. It has the following geographical coordinates: N 42° 58.847' and E 023° 35.731'.

IV. 4. Climate in the studied urban areas of Sofia and the village of Bistritsa

In climatic terms, the territory of Sofia and the village of Bistritsa fall within the Moderately Continental climatic subregion, which is the climatic region of the highlands of Western Central Bulgaria. It encompasses specific basin-like areas located in the western part of Central Bulgaria, which are surrounded by numerous low and moderately high mountains. In terms of temperature, the winters in the region are cold, similar to those in the Danubian Plain, but the summers are significantly cooler. characteristics of climate conditions are late spring and early autumn frosts, which are a result of the basin-like nature of the terrain. The annual precipitation pattern in this region has pronounced continental character. The maximum occurred in June, and the minimum in February. Furthermore, the difference between the summer and winter precipitation amounts is, on average, approximately 15%, approaching the values observed in the Danubian Plain.

V. Research Methods

V. 1. Field Investigations and Sampling

Field investigations encompassed all the soil-forming factors. The soils were studied by forming soil profiles and trenches. Sampling was conducted across soil horizons, and soil color characteristics were determined. The locations where the soils were sampled were geolocated using GPS and other software packages. Soil classification was performed according to the principles of the Bulgarian classification by Koynov et al.. and the World Reference Base for Soil Resources (WRB) in 2015.

V. 2. Methods for Determining Studied Soil Parameters

Primarily, classical methods were employed to determine the following soil parameters: Physical (Mechanical composition of soils - according to the Kachinsky method and mathematical correlation for soil texture recalculation based on FAO classification); Physicochemical parameters (soil pH, sorption capacity, composition of basic cations, and degree of base saturation); Chemical parameters (salinity, carbonate content, total organic carbon and humus, composition of soil organic matter, optical densities of humic acids, total nitrogen content, mobile forms of mineral nitrogen, mobile forms of phosphorus and potassium, heavy metal content - Mn, Zn, Cu, Fe, Cr, Pb, Ni, and Co, humus nitrogen enrichment, degree of soil humus reserves); Biological parameters (abundance of major groups of soil microorganisms by depth of soil profile, total biological activity, amount of total microbial biomass, microbial metabolic coefficient (qCO2), urease, invertase, phosphatase, and peroxidase activities); Radioisotope studies (specific concentration/activity per unit soil mass of radionuclides, cesium-137, uranium-238, thorium-232, radium-226, and potassium-40, Pb-210, radium equivalent activity /Ra_{eq}/, external hazard index /H_{ex}/).

V. 3. Statistical Methods for Analysis of Obtained Results

Statistical data processing included determining the standard deviation among replicates of each sample and general descriptive statistics using the Excel 2013 software package. Data on CO_2 production, total microbial biomass, and enzymatic activity were statistically processed using analysis of variance (STATGRAPHICS. Plus 2.1).

VI. Results and Discussion

VI. 1. Genetic and Classification Characteristics of Studied Urban Soils. Plant Diversity.

Profile 1. Based on the conducted research, the soil was classified as follows: anthropogenically overlapped moderately leached smolnitsa, loamic - Bulgarian classification, and Urbic Technosol (Eutric, Humic, Loamic, Transportic) over Pellic Vertisol (Chernic, Endocalcaric) - WRB classification. The terrain in the surrounding area was flat. The presence of stones and pebbles in the surface layer classifies the soils as weakly stony (up to 5% of the horizon volume), whereas the content of artifacts is nearly triple. Subsoil water was not detected within the profile boundaries, and according to the data, it lies at a depth greater than 18 m, thus not influencing soil-forming processes. The original smolnitsa soils were composed of organic clays overlying a layer of gray-brown Pliocene clays containing varved cores. These soil-forming Pliocene clays were found below 180 cm in the studied soils. The overlying layers exhibit the characteristics of a cultural horizon and consist of earthy carbonate masses mixed with household waste, stones, and pebbles. The formation of a cultural horizon in the soils of Sofia has been considered a natural phenomenon typical of human habitats since ancient times. However, the microrelief suggests the artificial deposition of this layer, which is reflected in the classification of these soils. The vegetation is predominantly meadow, with the dominant species being Kentucky bluegrass (*Poa pratensis*), which forms a dense cover and occupies up to 77% of the studied area. This was followed by cock's-foot grass (*Dactylis glomerata*), 20%, plantain (*Plantago major*) at 2%, and 1% clover (*Trifolium sp.*). Occasionally, individual shrubs such as dog roses (*Rosa canina L.*) and trees such as lindens (*Tilia cordata Mill*) and plums (*Prunus domestica*) can be found. This green area was maintained through mowing and standard pesticide treatments.

Profile 2. It characterizes another newly formed soil type: technogenic soil, moderately deep, loamic, moderately stony, or Urbic Technosol (Amphiskeletic, Calcaric, Mollic, Transportic). Located in a terraced terrain formed as a result of earth filling at an altitude of 601 m above the sea level. These soils are formed by covering the original soils with earth materials that mimic the soil-forming materials of nearby moderately leached smolnitsa, cinnamon-like, moderately deep carbonate Quaternary brown alluvial clays, and Pliocene sands. The degree of stoniness in the newly formed soils was moderate in the surface horizon and increased sharply with depth. In addition to their strong fragmentation from stones and artifacts, these soils have no other conditions that could limit their productivity. The subsoil water is outside the profile boundaries. The vegetation is mainly meadows interspersed with belts of woody vegetation, including white poplar (*Populus alba*). The dominant plant species is cock's-foot grass (*Dactylis glomerata*), comprising up to 80% of the area, followed by bird's-foot trefoil (*Lotus corniculatus L.*) at 10%, yellow sow thistle (*Leontodon rilaensis*) at 5%, and a variety of other plant species, including chicory (*Cichorium*) and thistle (*Onopordum acanthium*).

Profile 3. Located in a moderately leached Cinnamon forest soil, loamic, slightly to moderately leached, Chromic Endocalcic Luvisol (Differentic, Profondic Humic, Clayic) at 625 m above sea level. It has been intersected and further fragmented by anthropogenic activities (soil excavation) in the surrounding area. As a result of excavation activities near the profile, earth materials were removed, and a micro-depression with a height of 2 m and area of 600 square meters was formed. Consequently, the soil difference in this area has almost been destroyed and is limited to a strip with a width of 8-16 meters and a length of 90 m. The soil-forming materials consist of quaternary deluvial-proluvial materials, characterized by coarse unsorted and unstratified horizontal and vertical cobblestones and gravelly sandy deposits. These Quaternary deposits overlay Pliocene sediments, represented by yellow-rusty clays with a layered structure, typically carbonate, clays with a sandy matrix, and gravel. The vegetation is primarily meadow, with the dominant species being blue moor grass (*Sesleria caerulea*), covering up to 75% of the area, followed by common agrimony (*Agrimonia eupatoria*) at 20%, and other species from the variety, including lily (*Liliaceae*) at 2%, wild strawberry (*Fragaria vesca*) at 2%, and oxeye daisy (*Chrysanthemum leucanthemum*) at 1%. Subsoil water is outside the profile boundaries.

Trench 1. It is located in the same soil variation as Profile 3 (Moderately leached Cinnamon forest soil, loamic, slightly to moderately leached) but in close proximity to the road at 623 m above sea level. It has been intersected and further fragmented by terrain due to road construction. The trench was taken from the surface layer, the A-horizon, with a depth of 30 cm.

Profile 4. Located in alluvial-meadow soil, moderately deep, slightly stony, or Hypereutric Fluvisol (Loamic, Somerimollic) at 556 m above sea level with flat terrain in the surrounding area, further fragmented due to anthropogenic activities such as road and heat transmission facility construction. Soil-forming materials consist of alluvial deposits from the Iskar River, mainly large cobbles, gravel-sized deposits, and a sandy matrix (Yaneva et al., 1992, 1995; Bozhinova-Haapanen, 2014). These alluvial deposits overlay a Pliocene substrate composed of sand, and more frequently gray and green-colored clays. Subsoil water is outside the profile boundaries. The degree of stoniness varies from weak to strong. The vegetation is primarily meadow with the dominant species being common windgrass (*Apera spica-venti*), covering up to 55% of the area. Fragmented populations of other species are also present, including four-seeded vetch (*Vicia tetrasperma*) - up to 35%; common wormwood (*Artemisia absinthium*) - 5%; Kentucky bluegrass (*Poa pratensis*) - 3.5%; common catchfly (*Silene vulgaris*) - 1%, and individual narrow-leaved pea (*Lathyrus nissolia L.*).

Profile 5. The soil is characterized as alluvial-meadow soil, deep or Hypereutric Fluvisol (Epiclayic, Endoloamic, Pachic) according to the WRB, located at an elevation of 561 m above sea level, with a flat terrain in the surrounding area. In addition to stratification caused by river deposits, the influence of soil-forming processes with biogenic characteristics was observed. Well-developed vegetation, which includes more plant species than the adjacent areas (and therefore raises suspicions of additional artificial grassing), leads to a stronger differentiation of the profile and the formation of a deeper humus horizon. The vegetation is predominantly meadow, with equal proportions of field clover (*Trifolium campestre*) and black medick (*Medicago lupulina*) dominating, covering up to 35% of grassland (up to 70% in total). Other species in the grassland association included red clover (*Trifolium pratense*), 10%; yellow vetch (Vicia lutea), 8%; and yarrow (*Achillea millefolium agg.*) - 6%; cock's-foot (Dactylis glomerata) - 3-4%; and Kentucky bluegrass (*Poa pratensis*) - 2-3%. The soil-forming materials are alluvial Quaternary sandy-loamy clays located above sand and gravel with a Pliocene age. Subsoil water is outside the profile boundaries.

Profile 6. Strongly leached smolnitsa, extremely deep, heavy sandy-loam. WRB classification: Pellic Vertisol (Hypereutric, Mollic, Profundihumic). It is located in flat terrain with a slight northeast slope at 561 m above sea level. These soils have the same stratigraphy as the urbanogenic smolnitsa, except for the absence of a cultural horizon. One of the main morphological characteristics of these soils is their tar-like black color, which is a relic feature of the hydromorphic stage of their formation and the absence of argillic pedoturbation (pocket-like protrusion of soil-forming materials). Together with the structure, low humus content, and distribution of mechanical elements, these characteristics formed the main diagnostic features of the studied smolnitsa soils. The obtained data suggest that these smolnitsa soils delineate the boundary of the distribution of moderately leached, lightly clayey smolnitsa soils located nearby. In this previously unexplored soil zone, different varieties of leached smolnitsa soils with varying mechanical compositions were formed, which requires more detailed research. As in Profile 1, the groundwater level was outside the profile boundaries and did not influence the genesis of these soils; it was moderately deep (10-30 m). The parent Pliocene clays were located below 190 cm. The vegetation is mixed and consists of woody species: linden (*Tilia cordata Mill*), birch (*Betula*), spruce (*Picea*), and ash (*Fraxinus excelsior*); herbaceous vegetation composed of blackberry (*Rubus fruticosus*), clover (*Trifolium*), coltsfoot (*Tussilago farfara*), Kentucky bluegrass (*Poa pratensis*); and moss cover. In this green zone, introduced species like hazelnut (Corylus) and ornamental garden plants such as roses (*Rosa*), tulips (*Tulipa*), snowdrops (*Galanthus*), crocuses (*Crocus*), lily of the valley (*Convallaria majalis*), and fragrant violet (*Viola odorata*) can be found. Green areas were maintained using standard treatments.

Profile 7. Leached smolnitsa (secondarily carbonated), deep, slightly clayey. WRB classification: Pellic Vertisol (Amphihumic, Hypereutric), located at an elevation of 583 m, with a flat relief in the surrounding area. These soils exhibited significant deposition of coarse and fine powder particles on the surface and slight enrichment of the surface horizon with alkaline agents (effervescent small stones). The degree of stoniness was low, and the groundwater was outside the profile boundaries. The soil-forming materials consist of Pliocene clays. The vegetation is mixed: shrubby with representatives like lilac (*Syringa*) and dog rose (*Rosa canina*); broad-leaved woody species including birch (*Betula Pendula*), horse chestnut (*Aesculus hippocastanum*), and ground-covering herbaceous vegetation such as annual meadow grass (*Poa annua*), Kentucky bluegrass (*Poa pratensis*), and cock's-foot (*Dactylis glomerata*).

Trench 2. Leached smolnitsa (additionally carbonated), deep, slightly clayey. WRB classification: Pellic Vertisol (Amphihumic, Hypereutric). In this section, the dusting of the surface horizon was less pronounced and the color at depth was more intense black.

Profile 8. Cinnamon forest soil, slightly leached, moderately sandy-loamy. WRB classification: Chromic Luvisol (Endoclayic, Epihumic, Epiloamic) at an elevation of 929 m above sea level and in the lowland area of the surrounding terrain. These soils were formed on non-carbonated sandy-loamy materials under the influence of cultivated vegetation: ryegrass (Lolium), flowers, and pears (Pyrus). No subsoil water was detected.

As a result of the conducted research, the following morpho-genetic units are identified in the surveyed areas:

- Soil influenced to varying degrees by urbanization effects - urbanogenic-covered moderately leached smolnitsa (profile 1), newly formed urbanogenic (anthropogenic) soil (profile 2), moderately leached Cinnamon forest soil, slightly to moderately leached (profile 3 and trench 1), and leached smolnitsa, slightly clayey (profile 7 and trench 2);
- Soils with an undisturbed profile - alluvial-meadow soil, moderately deep (profile 4); alluvial-meadow soil, deep (profile 5); strongly leached smolnitsa, super-deep (profile 6); and cinnamon forest soil, slightly eroded (profile 8).

According to the prepared soil profiles, the smolnitsas from the surveyed areas possess the main characteristics of the leached smolnitsa subtype, but differ with weakly expressed vertic features.

Construction of infrastructure objects in the surveyed recreational and peripheral suburban areas of Sofia City led to fragmentation of the soil cover and reduced soil diversity. In most cases, these negative impacts are associated with the artificial deposition of surface layers of earth masses with high skeletal content and low fertility. Less frequently, cases of soil diversity loss resulted from the removal of productive soil horizons. In the specific case, this activity does not lead to complete destruction of the moderately leached cinnamon forest soil but restricts the distribution of their range.

Despite their short genesis, the newly formed soils have well-structured and moderately to very high humus A-horizons with an average depth. Because these horizons are moderately sandy-loamy and fragmented by stones and artifacts (of mineral origin), they are moderately compacted. Both the surface and deeper horizons of profiles 1, 2, 7, and 8 exhibited a weak alkaline reaction of the environment and a high buffering capacity against acidification.

The surveyed green areas in Sofia City are habitats for a rich diversity of plants with local and exogenous origins. Despite biocidal treatments, this vegetation provides conditions for the life of ground fauna, including garden snails (*Helix pomatia*), small white snails, annelid worms (*Annelida*), ants (*Formicidae*), and spiders (*Araneae*).

VI. 2. Chemical and Physicochemical Characteristics

VI.2.1. Sorption Capacity

Globalization processes at the beginning of the 21st century have led to an increase in the ecological vulnerability of urban areas. Among the preferred indicators for the initial assessment of the ecological status of soils are physicochemical parameters such as pH and cation exchange capacity.

Soils created as a result of urbanization (profiles 1 and 2) are characterized by a very weakly alkaline reaction of the environment and primarily have medium carbonate content (in the range of 3-5%). They have average colloid activity (T8.2, ranging from 30 to 45 cmol/kg, Table 24) according to the classification by Ganev, and sorption interactions related to the functioning of weakly acidic positions on mineral colloids as acid-hydrogen complexes. Because of the presence of carbonates, this acid-hydrogen form of weakly acidic positions, that is, the exchange retention of hydrogen cations on weakly acidic positions of mineral colloids instead of basic cations, can be considered a physicochemical characteristic of clay minerals associated with the hydromorphic stage of soil development. It can be assumed that hydrated clay minerals, such as vermiculite, are present here, which is characterized by both increased magnesium content (in extracts from the surface horizon with "royal water," the magnesium content is higher than calcium content by more than two times) and the ability to replace basic calcium and magnesium ions with hydrogen ions due to the autoionization of water. The low sorption capacity also suggests the absence of smectites in their pure form, and the transformation of biotite found in smolnitsa into vermiculite explains their presence. Despite its increased content, Mg is not the primary exchangeable cation and does not lead to Mg salinization.

The adsorption of hydrogen ions onto the weakly acidic positions of clay minerals is better pronounced in the buried horizon of the smolnitsa (profile 1), where the magnesium content (675 mg/kg in A1b horizon) in the soil extracts with "aqua regia" is lower than the calcium content (1445 mg/kg). This demonstrates that, in addition to mineralogy, water flows, biogenic processes, and the development of ecosystems as a whole also determine the physicochemical interactions in smolnitsa soils. Because of the presence of hydrolytic acidity (pH 8.2), the degree of base saturation is below 93%, which is considered a critical minimum for the absence of harmful soil acidity. Harmful acidity is not related to the presence of toxic aluminum (Al) and its potential desorption into the soil solution; it is limited only by the destabilizing role and chemical activity of exchangeable hydrogen.

In the urbanogenic (anthropogenic) soil (profile 2), hydrolytic acidity sharply decreased below a depth of 21 cm (more than two times), positively affecting their physicochemical conditions, although these layers had a weaker biological and ecological significance. This is also the only profile where the presence of vermiculite cannot be expected (as we mentioned, the indicator is a higher magnesium content than calcium), and hydrolytic acidity in the surface horizon is due to biogenic processes and predominant cereal plant species.

In the moderately leached Cinnamon forest soil, slightly to moderately eroded (profile 3), carbonates from the surface layers neutralized the acidic products generated by the biodegradation processes. This gradually leads to depletion and acidification of the environment to a pH of 5.9. In addition to hydrolytic acidity, toxic exchange acidity (exchangeable Al > 0.2 cmol/kg) is also observed in this soil. Although it is not high, exchange acidity worsens the soil environment and suppresses plant growth. Typically, exchange acidity develops as a result of the acidic degradation of clay minerals, which is also reflected in the ratios of T8.2 in Ah/T8.2 in Ck < 1 and T8.2 in Bt3k/T8.2 in Ck > 1. Degradation in Ah was moderate, indicating a weak process of degradation of the colloid structure.

The moderately leached cinnamon soil also had a moderately high sorption capacity but a weaker buffering potential, which, as noted, decreased due to increasing acidity in the surface horizons. The strong proportional relationship between hydrolytic acidity and the degree of base saturation demonstrated this trend.

The alluvial-meadow soils of the Iskar River valley (profiles 4 and 5) were formed from sediments with varying amounts of gravel. The alluvial-meadow soil (profile 4) was moderately colloidal ($T_{8.2}$ from 20 to 30 cmol/kg) with a high neutralizing potential (above 80 cmol/kg). Acidic conditions in these soils are also associated with hydrolytic acidity and the acid-hydrogen form of weakly acidic positions on mineral colloids. These soils do not contain carbonates and have a weakly acidic soil reaction (pH 6.1-6.9). Throughout the profile depth, the studied indicators exhibited the typical distribution observed in genetically old soils and did not follow lithological differences between individual horizons.

The alluvial-meadow soils (profile 5) are moderately colloidal (T8.2 from 30 to 45 cmol/kg) and mostly moderately acidic (pH 5.1-6.0). They had the highest hydrolytic acidity among the studied soils and, accordingly, the lowest degree of base saturation throughout the depth, which determined a moderate level of harmful acidification according to the indicators defined by Regulation No. 4 (2009) and Order No. RD-619/15.09.2009.

The strongly leached smolnitsa soil (profile 6) clearly demonstrates the characteristic features of smolnitsa soils located in the peripheral part of the previously unexplored soil zone. These are neutral, strongly colloidal soils with a high neutralizing potential that decreases in Ah and A" as a result of the listed hypergenic processes. These soils also have a low amount of weakly acidic charges (TA) in the humus horizon, which can be regarded as a result of the slow, *in situ* transformation of biotite into vermiculite, implying the absence of defects in crystal structures (due to lack of transport) and the weak development of lateral surfaces. These processes were more pronounced in the last sub-horizon, where the content of weakly acidic positions was the lowest, and the content of exchangeable magnesium was the highest.

The high colloidal nature of soils from the first two morphological groups determines the strong proportional relationship between exchange acidity and base saturation ($R^2 = 0.98$ in smolnitsa soils and

$R^2 = 0.97$ in cinnamon forest soils), which decreases in soils with a layered structure ($R^2 = 0.64$) as their colloidal content, respectively, their buffering capacity decreases.

According to the quantitative classification system, the leached smolnitsa (profile 7 and trench 2) was characterized by a weakly alkaline soil reaction and low carbonate content. The very low acidity (TA) also explains the absence of exchange acidity (exchange Al) and the very weak hydrolytic acidity (exchange H8.2). This soil is moderately colloidal (T8.2 from 40 to 45 cmol/kg) and has the highest neutralizing potential of all studied soils. Here, a greater base saturation of the strongly acidic ion exchanger of the soil adsorbent (Bases>TCA) was observed, indicating contemporary clay formation in the leached soils.

The physicochemical state of cinnamon forest soil (profile 8) was as follows: the soil had a slightly acidic to neutral soil reaction with no carbonates throughout the profile. It has moderate colloidal properties, decreasing vertically, and moderately high sorption capacity. Weakly acidic charges are of a small proportion and are mostly occupied by hydrogen cations. Harmful acidity was not observed in the soil.

Limited knowledge of urban soils has sparked interest in studying their humus status as an indicator of their ability to support terrestrial ecosystems in urban environments.

In terms of the degree of humus enrichment by nitrogen, most profiles exhibit moderate to high enrichment, with a C:N ratio between 9 and 15 (Gyurov and Artinova, 2015). One exception is profile 2, where the upper two horizons have very low and low enrichment, respectively.

The shallow Ah horizon of profile 1, which had a very high humus content of 5.52% (Table 14), formed over a relatively short period of approximately 45 years. The humus is of the Mull type, and humic acids Ch/Cf > 2.0 (Table 25) predominate throughout the profile. They have a high degree of condensation (E4/E6 = 3.87), making them hydrophobic and poorly mobile polymers strongly bound to the mineral matrix owing to the high content of calcium humates. Low-molecular-weight fractions of fulvic acids (aggressive ones) are also present in the soil, gradually decreasing with depth (from 0.8 to 0.4 g/kg within the profile).

Deeper but less humic epipedons (2.59% humus in Ah, Table 15) were formed in moderately humic anthropogenic soils (profile 2). Its main characteristics include well-humified organic matter (Cha: Ctotal × 100, in % = 17.33%), mature rhizomul humus, and a high degree of condensation (E4/E6 = 3.50) of strongly dominant humic acids (Ch/Cf = 3.25). The organic carbon content sharply decreased in the lower horizons, where only fulvic acids were detected (up to 33% of the total carbon).

In the humus-accumulative horizon (Ah) of the cinnamon forest soil (profile 3), the predominance of humic acids was the least pronounced (Ch/Cf = 1.17), and the degree of condensation of aromatic nuclei was the lowest (E4/E6 = 4.08). This did not significantly alter their hydrophobicity and poor mobility, and according to the obtained results, fulvic acids primarily constituted the mobile fraction, reaching up to 58% of the total extractable humic acids. The weakly acidic reaction of the medium (pH in water 5.9) undeniably contributed to the increased mobility of organic matter. The correlation between pH and the mobile fraction of humic acids was demonstrated by a statistically significant correlation (R2 = 0.73), primarily driven by the correlation between fulvic acid content and pH (R2 = 0.85).

The status of SOM in the next three profiles (4, 5, and 6) differed from that in the upper three. They are characterized by similar contents of humic and fulvic acids or the absence of fulvic acids (profile 4). Humic acids are stable, highly condensed polymers with moderate to high nitrogen enrichment (C:N ratio values ranging from 10.54 to 14.52).

In profile 7, the humus was of the Mull type, as indicated by the strong predominance of humic acids (Ch/Cf > 2.0) (Table 25). The degree of condensation of humic acids was also high (E4/E6 = 3.65). They are strongly associated with the mineral part of the soil because of the high calcium humate content. The low-molecular-weight fraction of fulvic acids is 0.4 g/kg throughout the profile.

The cinnamon forest soil (profile 8) is moderately enriched with humus (2.74%) in the surface horizon (Ar1), which morphologically resembles the humus-transitional horizons in natural analogs. The Cx/Cf ratio was the lowest in this epipedon (0.98), whereas the degree of condensation (E4/E6 = 5.02) was the highest among all the studied soils.

Interesting statistical information can be observed regarding organic carbon: its average content in the surface horizons of the studied profiles - 18.2 g/kg is close to the average content (19.1 g/kg) in the surface horizons of pastures in Bulgaria, but higher than that in the surface horizons of pastures in the Sofia Basin.

VI.2.3. Mobile Forms of Nitrogen, Phosphorus, and Potassium

The ability of soil to meet the nutritional needs of plants is determined by the content of assimilable forms of nitrogen, phosphorus, and potassium. Despite their good humus content, the examined soils varied in terms of their reserves of assimilable forms of these essential macronutrients such as nitrogen, phosphorus, and potassium. It is noteworthy that there is a high content (> 23.0 mg/kg) of assimilable nitrogen (Σ NH4+NO3) in urban-influenced moderately leached smolnitsa soil and technogenic soil, which only slightly decreases with depth. This indicates that the processes of deposition and mineralization of organic matter are more intensive than those of nutrient uptake, leading to their accumulation. The dense vegetation cover of these soils also plays a significant role in these processes by acting as a shield to protect the soil surface from moisture evaporation, nitrogen loss, and rapid temperature fluctuations.

The elevated content of NH_4^+ and NO_3 in profiles 1, 2, and 3 may be linked to the introduction of urea into the soils caused by human activity, which may lead to a higher degree of ammonification and accelerate the nitrogen cycle. In soils where nitrogen humus enrichment is close to 10 (profiles 4, 5, and 6), the primary additional source of nitrogen is greenhouse gas emissions (or their precursors, NOx, CO, and non-methane volatile organic compounds), which can also affect the nitrogen transformation cycle. The higher soil temperatures in profiles 4, 5, and 6 (up to 3-4° C) support the assumption of nitrogen mineral differentiation during anthropogenic influences, despite the significant correlation between total nitrogen and organic carbon.

The high contents of phosphorus (P) and potassium (K) in profiles 1, 2, and 3 are likely due to the high concentration of total phosphorus and total potassium in the newly formed A horizon of profile 1. In the deeper horizons (II and A1b) the content of available forms of these elements sharply decreases, which is related to the decreased humus content. The strongly leached smolnitsa (profile 6) exhibited similar properties. This clearly overlaps with the characteristic features of smolnitsas from the peripheral zone. The content of available P in A horizon was 20.7 mg/100 g, which categorizes this soil horizon as moderately stocked. The deeper horizons were very poorly stocked with phosphorus. The K content did not change with depth in the profile, and remained high.

In the case of the leached smolnitsa located near "Shosse Bansko Street" (profile 7 and trench 2), the contents of the nutrient elements P and K are similar to those of natural, non-anthropogenically influenced leached smolnitsas (Filcheva et al., 2013). Natural soils have a thick humus horizon and are insufficiently stocked with nitrogen and phosphorus, but have a favorable potassium regime, which is also observed in the studied soils (Penkov, 1983). In the studied profile, mobile P increased with depth, likely due to the high phosphorus content in the parent rocks on which the soil-forming process occurred. Because it is very poorly stocked with P in the surface horizon, the soil becomes very highly stocked in the C horizon. A similar trend was observed for available K, with values increasing with depth in the profile. In conclusion, this soil had a good nutritional status.

Representative cinnamon forest soils were Profiles 3 and 8. Natural cinnamon forest soils are characterized by good nitrogen and potassium content and moderate phosphorus content.

Data for the moderately leached cinnamon forest soil, slightly to moderately eroded (profile 3) showed very low phosphorus content in the shallow humus-accumulative horizon (Ah) and almost no available phosphorus in the Bt and Bt2 horizons, making this soil have an unfavorable phosphorus regime. The available potassium in all horizons of the profile was within the moderate content range.

The soil from the village of Bistritsa (profile 8) is very poorly stocked with phosphorus and has low potassium content throughout the depth of the profile.

Soils with undisturbed profiles were alluvial-meadow soils (profiles 4 and 5). The mobile forms of phosphorus (P) and potassium (K) in profile 4 gradually decreased with depth, whereas in profile 5, they exhibited a stratified distribution, similar to soils in pristine conditions. The degree of potassium content was high, and phosphorus content was moderate in profile 5 and satisfactory and unsatisfactory in profile 4. Natural alluvial-meadow soils are fertile soils that form in the valleys of large rivers on gravelly sandy alluvial deposits. The diversity of soil-forming deposits determines a different depths of the humus horizon and different content of essential nutrients. Generally, these soils have a moderate humus content and a low content of essential macro-nutrients.

The main characteristics of the surface horizon in the technogenic soil (profile 2) indicated its very low phosphorus content (1.2 mg/100 g) and high potassium content (28.8 mg/100 g). The amount of plant-available potassium sharply decreased below 20 cm (more than three times), whereas phosphorus showed a weak increase. Despite the anthropogenic influence on this soil, the high content of plant-available nitrogen and K suggests a relatively good nutrient regime.

VI.2.4. Content of Heavy and Alkaline-Earth Metals

The concept of "heavy metals" includes iron and all metals heavier than it, i.e., with a density > 5 g/cm3. In very small quantities, some of these elements are essential for living organisms, most commonly as co-factors for enzymes involved in biochemical processes (Fe, Mn, Zn, Cu, Mo, Ni, Se), while others are known toxins (Cd, Pb, Hg). The toxicity of each element manifests at different concentrations depending on specific soil characteristics, such as pH and mechanical composition. Ecologically and biologically significant elements include As, Pb, Cd, Cu, Zn, Ni, Cr, Mn, and Fe.

Soil pollution is classified into three types: uncontaminated, lightly contaminated, and heavily contaminated. The boundary values for these degrees depend on the content and variation of heavy metals in soils, their chemical forms, potential mobility, their effects on living organisms, etc.. The adopted criteria for assessing their content were background, permissible, and maximum permissible concentrations according to Regulation No. 3, 2008.

In different urban soils influenced by human activities, the heavy metal content varies significantly; however, several main trends can be observed in this study.

The quantity of Pb in the examined soils varies considerably, and it is difficult to link to anthropogenic influences or soil-forming redistributions. Its content in all examined profiles is below the precautionary or respective maximum permissible concentrations, ranging from 4.5 mg/kg (profile 6, Ah horizon) to 45.5 mg/kg (profile 4, Ah horizon).

The total iron content determined with "aqua regia" varies widely. Profiles 3 and 8 had the highest content: moderately leached cinnamon forest soil and lightly eroded cinnamon forest soil, respectively. This is reasonable because the soil-forming materials of cinnamon forest soils in Bulgaria are rich in iron-containing minerals (e.g., hematite and goethite), which color the soil mass in cinnamon, light brown-yellow, or red hue. Natural heavy clayey soils, such as smolnitsi, also exhibit a high content of pseudo-total iron. In this study, such soils are moderately leached smolnitsa, urban-covered profile 1, leached smolnitsa (secondarily carbonated) - profile 7, and trench 2.

The Mn content had the highest values in profiles 2 and 7. Profile 4 has the lowest Mn content, and it is known that the chemical composition of alluvial-meadow soils greatly depends on the chemical composition of the sediments. Here, the distribution of heavy metals in the profile is not subject to pedogenic regularities but is related to the periodicity of river sediments. In profile 5, a greater difference in Mn content was observed between the humus horizons and layers, which could also be attributed to agricultural operations.

In all profiles, the contents of Zn, Cu, Cr, Ni, and Co were close to or lower than the background values in Bulgarian soils and did not pose an ecological risk. Therefore, anthropogenic activities accompanying urbanization in the studied areas did not lead to soil pollution with heavy metals.

The calcium content, although determined after the sample was mineralized with aqua regia and, therefore, did not show the total content, was very low in the alluvial-meadow soils of the Iskar River Valley (profiles 4 and 5). These soils are mainly formed on alluvial and proluvial deposits with varying mechanical composition and slightly acidic environmental pH (pH 6.1-6.7). This trend is interesting given the fact that calcium is a biogenic element, and the vegetation in these soils implies a more significant accumulation. In these soils, the low calcium content was also accompanied by low manganese content, indicating the weak intensity of soil-forming processes and minimal changes in the soil profile in these areas. In both profiles, the average Mg content was higher than that of Ca.

Representatives of cinnamon forest soils (profiles 3 and 8) significantly differed from each other in terms of the content of "pseudo-total" Ca and Mg and their behavior in the profile. The strong predominance of Mg over Ca down to a depth of 70 cm in profile 3 has been attributed to the destruction and transformation of the smectite-vermiculite mineral composition.

In profile 6, strongly leached smolnitsa, the content of "pseudo-total" magnesium (in aqua regia - from 565 to 607.5 mg/kg) is also higher than the content of calcium throughout the profile (420-560 mg/kg), which indicates strong leaching of carbonates, possibly in the form of iron carbonate, due to the low content of "pseudo-total" iron (from 1.06 to 1.30%). These data support Stranski's opinion that there is hidden weak podzolization in the black soils of Sofia that cannot be diagnosed based on typical morphological characteristics.

Soils created as a result of urbanization (profiles 1 and 2) were characterized by medium carbonate content (in the range of 3-5%). They also had similar average calcium and magnesium levels.

The highest content of "pseudo-total calcium" (from 9126.2 to 9764.3 mg/kg) and "pseudo-total magnesium" (from 1513.9 to 1525.9 mg/kg) is found in the leached smolnitsa (secondarily carbonated - profile 7). The high content of the basic elements Ca and Mg throughout the profile indicates that primary minerals such as calcite and dolomite play a significant role in soil formation. There is an enrichment of calcium in the surface horizon (Ah), which is likely a result of road construction, possibly carried out with limestone-containing fill materials or winter anti-icing treatments on the road.

The high content of "pseudo-total calcium and magnesium" in most of the studied urban soils determines their slightly alkaline reaction, lack of exchange acidity, and high sorption capacity.

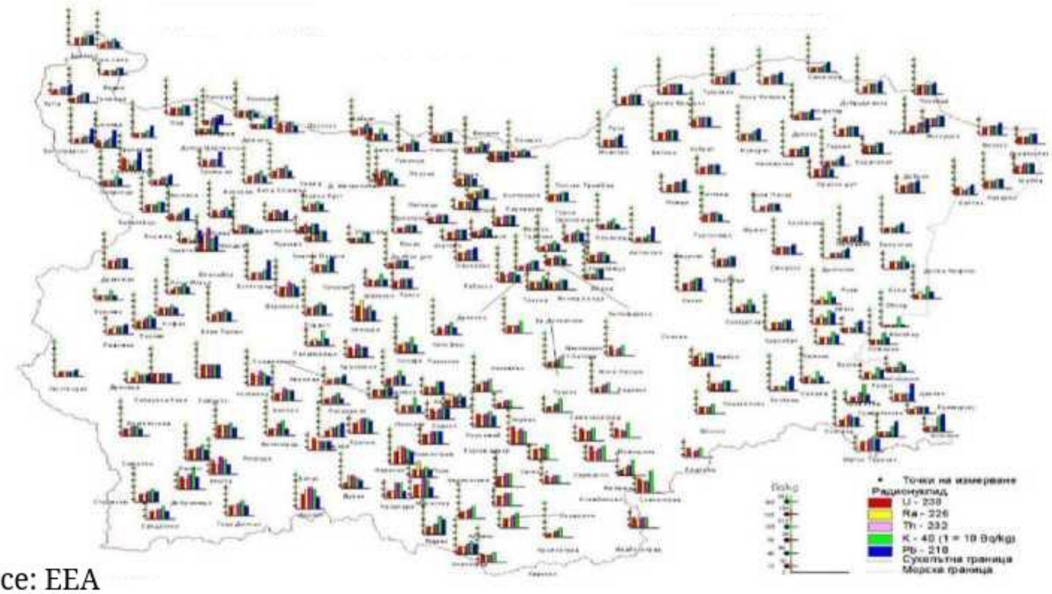
VI.3. Radioisotopic Characteristics of Studied Soils

To assess radiation risk, the Radium Equivalent (Raeq) and External Hazard Index (H_{ex}) were used. The permissible value of Ra_{eq} is 370 $Bq.kg^{-1}$. The maximum value of Hex is 1, which corresponds to the upper limit of Ra_{eq} (370 $Bq.kg^{-1}$), which is considered safe. Both indicators, the radium equivalent and external hazard index, suggested the absence of radioactive contamination. The average values of these two indicators, as well as the values by horizons, were far below the thresholds, indicating that there was no radioactive contamination in the studied soils.

Anthropogenic ^{137}Cs is known to spread and accumulate in the upper soil layers. This was confirmed by current data. According to the National Report on the State and Conservation of the Environment in the Republic of Bulgaria for 2021, the measured background values of ^{137}Cs in 445 points of untreated soils range from 0.18 to 14.8 $Bq.kg^{-1}$, with values above 200 $Bq.kg^{-1}$ considered high. As seen from the data, the content of ^{137}Cs in the studied profiles was in the range of <1 - 8 $Bq.kg^{-1}$, which suggests that the content of anthropogenic cesium is lower than that measured in untreated soils. It is noteworthy that in two of the profiles, profile 2 (technogenic soil) and profile 7 (leached smolnitsa, secondarily carbonated), the ^{137}Cs content was below the detectable limit (<1 Bq kg^{-1}) in all horizons. While for profile 2, which was created by filling with earth masses taken from deep soil layers, this is understandable, for profile 7, it is clear that it has not been affected by anthropogenic radioactive pollutants, despite its proximity to the road.

Radioisotope Pb-210 is another element that can be used to clarify anthropogenic loads on soils. The excess of the radioisotope ^{210}Pbex, that is, the quantity above its equilibrium concentration with ^{226}Ra (^{210}Pb$_{supp}$), is attributed to the deposition of radioactive dust and has anthropogenic origins in soils. Our data showed that the soils in the southeastern part of Sofia (profiles 1-6) were enriched to a greater extent with 210Pbex than the soils in the northwestern zone (profile 7, trench 2), delineating zones in the urban environment vulnerable to lead-210 anthropogenic loading. It was also observed that the distribution of ^{137}Cs and ^{210}Pb in the studied soils did not follow identical patterns, and the determination of only one of them could not be used for accurate assessment of anthropogenic radioactive contamination.

For the other natural radionuclides, the measured values in the eight profiles were in the following ranges: ^{238}U - 20-54 Bq.kg^{-1}, ^{226}Ra - 17-56 Bq.kg^{-1}, ^{232}Th - 24-51 Bq.kg^{-1}, and ^{40}K - 444-680 Bq.kg^{-1}. Compared to the data from the Executive Environmental Agency of Bulgaria (EEA) for 2019 (Figure 39), these fluctuations were much weaker:^{238}U - 14.1-89 Bq.kg^{-1}, ^{226}Ra - 16-82 Bq.kg^{-1}, ^{232}Th - 17-86 Bq.kg^{-1}, ^{40} K - 548-695 Bq.kg^{-1}.



Specific Activity of Natural Radionuclides in Undisturbed Soils, Bq/kg

Source: EEA

Figure 39. Specific Activity of Natural Radionuclides in Undisturbed Soils

VI.4. Biological Characteristics of the Studied Soils

VI.4.1. Abundance of Major Physiological and Morphological Groups of Microorganisms

Significant spatial heterogeneity in the physical and chemical properties of urban soils influences the diversity in the composition and abundance of microbial populations. The primary factors affecting the distribution of microorganisms in soil include water content, oxygen levels, nutrient availability, soil structure, and the composition and population density of soil fauna. These factors vary with depth in the soil profile and within soil aggregates.

The surface Ah horizon of the anthropogenically overlapped moderately leached smolnitsa (profile 1) was characterized by a relatively high abundance of all studied groups of microorganisms, except for actinomycetes. The large numbers of ammonifying bacteria ($19.27x10^6$ CFU/g) and cellulose-degrading microorganisms ($8.89x10^4$ CFU/g) indicate active processes of decomposition of easily accessible nitrogenous organic compounds and cellulose degradation (which occurs more slowly). Ammonifying bacteria and mineral nitrogen-assimilating bacteria had similar abundances. The ratio of the number of mineral-nitrogen-assimilating bacteria to that of ammonifiers is referred to as the mineralization index, and is an indicator of the direction of nitrogen transformation in the soil. The data obtained demonstrate a balance between the processes of mineralization of organic nitrogen compounds and immobilization of released mineral nitrogen in the microbial biomass. In horizon C1k, the bacterial population predominated, with their numbers remaining high. The other groups of microorganisms were less prevalent in this horizon.

In the surface horizon of the technogenic soil (profile 2), the quantities of ammonifying bacteria, spore-forming bacteria, and bacteria utilizing mineral nitrogen were similar to those obtained in the anthropogenically overlapped moderately leached smolnitsa (profile 1). Microscopic fungi were twice as abundant, and the number of cellulose-degrading microorganisms was smaller. With depth in the soil profile, the decrease in bacterial numbers was greater than that in profile 1, which is likely associated with a greater reduction in organic matter content in the horizon beneath the surface layer in this soil compared to the urban-covered moderately leached smolnitsa soil.

The moderately leached cinnamon forest soil, slightly to moderately eroded (profile 3) was characterized by a very high abundance of ammonifying bacteria in the humus-accumulative horizon. The presence of a large number of ammonifiers is likely due to the active release of root exudates, which are easily accessible nitrogen and carbon organic compounds. Ammonifying bacteria assimilate readily available organic nitrogen compounds (proteins and nucleic acids) and have the highest abundance in the root zone of plants. Their numbers were also very high in horizon Bt. In the surface horizon, spore-forming bacteria and microscopic fungi had a similar abundance to that of the technogenic soil (profile 2), while actinomycetes had three times higher numbers than profiles 1 and 2. The high abundance of ammonifying bacteria indicates the occurrence of intensive mineralization of nitrogen-containing organic compounds, and the high population density of actinomycetes indicates the degradation of more recalcitrant organic compounds in the soil. The ratio between ammonifying bacteria and bacteria utilizing mineral nitrogen in the surface soil layer was approximately 4:1, indicating that processes of mineralization of accessible nitrogen compounds dominate over immobilization processes. With depth in the soil profile, bacterial numbers remained high in horizon Bt, whereas the numbers of the other microbial groups decreased significantly. The obtained values for the numbers of microorganisms from the major groups in the Ah horizon were similar, and those for ammonifying bacteria were higher than those found for the surface horizon of weakly eroded arable soils of the same type from the Bankya district.

The alluvial-meadow soil (profile 4) is characterized by a high abundance of ammonifying bacteria, microscopic fungi, and actinomycetes in the A horizon. The ratio between the quantities of ammonifying bacteria and bacteria using mineral nitrogen was close to one, indicating an equilibrium between the processes of mineralization of easily assimilable organic nitrogen compounds by soil microflora and the immobilization of liberated mineral nitrogen in microbial biomass. The high abundance of microscopic fungi and actinomycetes suggests that the decomposition of incoming organic matter occurs at an advanced stage. Microscopic fungi and actinomycetes are known to actively decompose organic substances with more complex compositions, such as hemicellulose, cellulose, and lignin. Additionally, actinomycetes participate in both humus formation and humus decomposition processes. With depth in the soil profile, the abundance of microorganisms from most studied groups remained high.

For the Ah horizon of the alluvial-meadow soil (profile 5), significantly higher abundances of both ammonifying and spore-forming bacteria were observed compared with the respective horizon of alluvial-meadow soil (profile 4). These results, along with the two-fold higher number of ammonifying bacteria compared to the number of microorganisms using mineral nitrogen, indicate that the processes of mineralization of nitrogen organic compounds dominate in the alluvial-meadow soil (profile 5). Regarding the number of cellulose-degrading microorganisms, values close to those of alluvial-meadow soil (profile 4) were obtained. In the A" horizon, actinomycetes were also highly abundant, in addition to bacteria. The quantity of microorganisms from the mentioned groups was greater than that from the respective horizon of alluvial-meadow soil (profile 4). These results are likely associated with the presence of a larger amount of organic matter in the Ai horizon, as alluvial-meadow soil (profile 5) has a more substantial humus horizon than alluvial-meadow soil (profile 4). The obtained data for microorganism abundance in the studied alluvial-meadow soil (profile 5) are consistent with the findings reported by Nedyalkova et al. (2010) regarding the distribution of microorganisms with depth in the soil profile of a typical alluvial-meadow soil.

A high population ($42.5x10^6$ CFU/g) of spore-forming bacteria and cellulose-degrading microorganisms ($11.31x10^4$ CFU/g) was established for the strongly leached smolnitsa (profile 6). Spore-forming bacteria participate in the later stages of organic matter mineralization, degrading various organic compounds of different compositions (chitin, cellulose, hemicellulose, and others). The large number of spore-forming bacteria and cellulose-degrading microorganisms, as well as the relatively high count of actinomycetes, indicate that the degradation processes of less readily assimilated organic compounds dominate in this soil. In the A" horizon, the microbial population decreased significantly for all investigated groups, except for microscopic fungi, which, thanks to their spore-forming ability, survive under unfavorable environmental conditions. Changes in physicochemical conditions with soil depth (decreasing oxygen and organic matter content) also reduced microbial diversity, with a dominance of microorganisms adapted to low-oxygen conditions (microaerophilic species). The obtained data on the microbial population structure in this soil differed from those of cultivated leached smolnitsa from the experimental field of the Pushkarov Institute of Soil Science, Agrotechnologies, and Plant Protection in Bozhurishte (Petkova & Petkova, 2016). This is likely related to the influence of agricultural practices and plant cover, which, through root exudates, exert a specific influence on the development of soil microflora. The plant cover in profile 6 exhibited greater species diversity than the cultivated leached smolnitsa in Bozhurishte, where maize and barley were grown in crop rotation.

The leached smolnitsa located near "Shosse Bankya" Street (profile 7) is characterized by a very high population of ammonifying and spore-forming bacteria ($60.83x10^6$ CFU/g and $65.91x10^5$ CFU/g, respectively). These data are consistent with the results of Malcheva (2012), who also found an increase in the bacterial population in urban soils in areas with intense automobile traffic. Non-spore-forming ammonifying bacteria play a role in soil self-purification processes. Compared to the corresponding horizons of the other profiles, the bacterial population remained significantly higher in the A' horizon. Microscopic fungi had a low population in the surface horizon, possibly because of weakly alkaline reactions in the soil. Cellulose-degrading microorganisms and microorganisms utilizing mineral nitrogen were also sparsely distributed both in the surface horizon and in the horizons beneath it. Compared to Profiles 1 and 2, where the soils were formed by overlapping leached smolnitsa with carbonate materials, significant differences were observed in the populations of the investigated main soil microorganisms. The established structure of microbial populations in this soil significantly differs from that of microorganisms in cultivated leached smolnitsa from the experimental field of "Pushkarov" in Bozhurishte (Petkova & Petkova, 2016). The authors found a higher population of microscopic fungi and cellulose-degrading microorganisms, and a lower number of bacteria. These results can be explained, on the one hand, by the influence of agricultural practices on cultivated soil and plant cover and, on the other hand, by the anthropogenic load on the soil located near the automobile road.

Relatively high quantities of ammonifying and spore-forming bacteria were also detected in the surface layer of cinnamon forest soil (profile 8). In horizon Ap2, the number of ammonifying bacteria, spore-forming bacteria, and actinomycetes remained high. In comparison to the moderately leached Cinnamon forest soil, slightly to moderately eroded (profile 3), a significantly lower population of ammonifying bacteria, microscopic fungi, and bacteria utilizing mineral nitrogen was found in the surface layer of Profile 8. The low numbers of bacteria utilizing mineral nitrogen in Profiles 7 and 8, despite a high quantity of ammonifying bacteria, indicate that mineralization processes dominate over the processes of nutrient element immobilization in microbial biomass.

The presented data on the quantities of microorganisms from the main morphological and physiological groups show that the studied urban soils are characterized by high biogenicity in the surface soil horizon, which decreases with depth in the individual profiles, depending on specific soil conditions. Among the studied groups of microorganisms, ammonifying bacteria had the highest population density and dominated the surface horizon of all soils. The most populous groups are actinomycetes, bacteria utilizing mineral nitrogen, and spore-forming bacteria. Microscopic fungi and cellulose-degrading microorganisms have population densities two orders of magnitude lower. In the surface horizon of the studied soils, the highest numbers of ammonifying bacteria and microscopic fungi were found in the leached cinnamon forest soil, the highest number of actinomycetes in the alluvial-meadow soil (profile 4), and the highest number of cellulose-degrading microorganisms in the strongly leached smolnitsa.

Data on the population of microorganisms associated with nitrogen transformation (ammonifiers and bacteria utilizing mineral nitrogen) show that the processes of organic nitrogen compound decomposition dominate nitrogen immobilization processes in the leached cinnamon forest soil, alluvial-meadow soil, leached smolnitsa, and cinnamon forest soil. Mineralization of organic matter entering the soil is in a more advanced stage in the strongly leached smolnitsa and alluvial-meadow soils (profile 4).

VI.4.2. CO_2 Production, Microbial Biomass Carbon, and Enzyme Activity

From the data in Figure 40, it can be seen that the CO_2 production in the studied soils varies widely (from 4.95 to 18.99 mg CO_2/100 g soil/24 h), indicating that the processes of organic matter mineralization within them occur with different intensities. The average CO_2 production was 11.61 mg/100 g/24 h. The highest and statistically proven value for this indicator was obtained in the anthropogenically overlapped moderately leached smolnitsa (profile 1) - 18.99 mg/100 g soil/24 h. This result can be explained by the high content of organic matter and mineral forms of nitrogen, phosphorus, and K in the surface layer (Table 26), which creates favorable conditions for the development of vegetation cover. This, in turn, promotes the input of larger quantities of plant residues from grass biomass, which are mineralized by heterotrophic microflora. CO_2 production is also relatively high in the technogenic soil (profile 2) - 15.41 mg/100 g/24 h. In the other soils, except for the cinnamon forest soil where CO_2 production is the lowest, the overall biological activity is relatively similar and ranges from 9 to 12 mg CO_2/100 g soil/24 h."

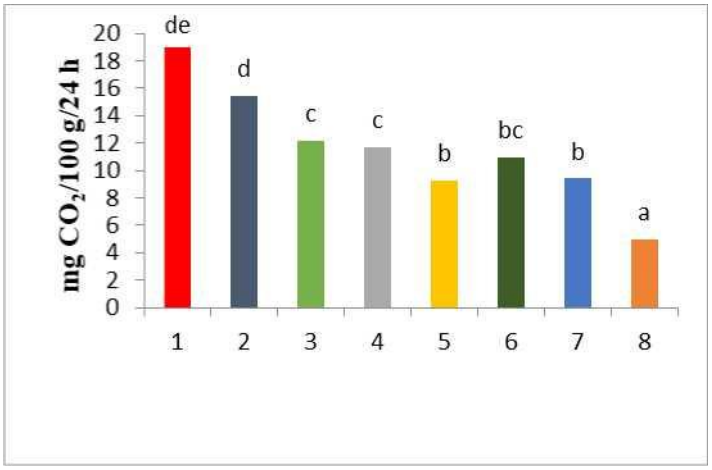


Figure 40. CO_2 in urbanized soils

Legend: 1. Anthropogenically overlapped moderately leached smolnitsa, 2. technogenic soil, moderately deep, 3. *moderately leached Cinnamon forest soil, slightly to moderately eroded, 4. alluvial-meadow soil, moderately deep, 5. alluvial-meadow soil, deep, 6. strongly leached smolnitsa 7. Leached smolnitsa (secondarily carbonated), deep, slightly clayey, 8. Cinnamon forest soil, slightly leached. *(Different letters of the bars show that values differ at level of probability P<0.05)*

Microbial biomass is a labile reservoir for essential plant nutrients (N, P, and S). Incorporating these elements into microbial cells protects them from loss through leaching or fixation by clay minerals in the soil. During the mineralization of dead microbial cells, these nutrients become available in a form accessible to plants. Soil microbial biomass increases or decreases depending on the composition and quantity of plant residues entering the soil and the conditions for their decomposition, which can be faster than that of soil organic matter. Therefore, changes in microbial biomass are early indicators of changes in soil conditions related to the acceleration or deceleration of organic matter degradation in the soil (Brookes, 2001).

The highest values for microbial biomass carbon in the examined soils were obtained for urban-covered and alluvial-meadow soils, with 46.28 and 46.15 mg C/100 g soil, respectively. A relatively high microbial biomass carbon content was also found in the eroded cinnamon forest soil and alluvial-meadow soil. The lowest values of this indicator were recorded for profiles 2, 7, and 8, with 15.45, 14.37, and 14.25 mg C/100 g soil, respectively. These values were two to three times lower than those of the other profiles.

Based on the obtained data for CO_2 production and microbial biomass C, the metabolic quotient (qCO_2) of microbial populations in the examined soils was calculated. The metabolic quotient reflects the efficiency with which microorganisms utilize nutrients in the soil, and increases under stressful conditions, which reduces this efficiency. The data show that the highest values for this indicator were observed in urban-covered soil and eroded smolnitsa soil. For other soils, the metabolic quotient had similar and significantly lower values. The obtained data for the metabolic quotients of microbial communities for profiles 2 and 7 showed a tendency toward unfavorable changes in the microbial balance. Several studies have reported a decrease in microbial biomass and an increase in the metabolic quotients of microorganisms in urban soils under anthropogenic stress. The observed difference in the metabolic quotient of profile 2 compared with the other soils may be related to the presence of a large number of artifacts, creating local zones with altered chemical properties and reduced biological activity.

In conclusion, the studied urban soils varied significantly in CO_2 production and microbial biomass C content. The highest values for these indicators were obtained for urban-covered smolnitsa, moderately leached cinnamon forest soil, and alluvial-meadow soil (profile 4). Anthropogenic soil is characterized by high CO_2 production and low microbial biomass C content. The higher metabolic coefficient of this soil indicated a possible negative anthropogenic influence. A similar but less pronounced trend was observed for the smolnitsa soil (profile 7).

In the field of soil enzymology, extensive research has focused on the impact of heavy metal pollution resulting from industrial activities, automotive transport, and the use of plant protection products on the soil biota. Changes in the enzymatic activity of urban soils due to urbanization have not been extensively studied. The activities of urease, invertase, acid phosphatase, and peroxidase were determined in the surface layer of the studied soils. These enzymes are involved in the cycling of the essential biogenic elements N, P, and C. Urease catalyses the hydrolysis of urea to NH_3 and CO_2. It enters the soil through plant residues, livestock manure, and mineral nitrogen fertilizer (urea). Additionally, it is formed in the soil as an intermediate product in the degradation of proteins and nucleic acids. Urea hydrolysis (NH_3/NH_4^+) is an accessible nitrogen source for plants. Therefore, urease activity in soil is crucial for fertility and is used as an indicator of soil quality.

From the data presented in Figure 43, it can be seen that urease activity in the studied soils ranges from 1.56 to 6.54 mg NH_4-N/100 g soil/h. The highest urease activity was observed for the moderately leached

Cinnamon forest soil, slightly to moderately eroded (profile 3) and the anthropogenically overlapped moderately leached smolnitsa (profile 1). Technogenic soil (profile 2) exhibited the lowest urease activity. The recorded value for this profile is approximately three times lower than that of soils with high activity, indicating a slow oxidation rate of organic nitrogen compounds or a deficiency of such compounds. The low urease activity of profile 2 corresponded to the low microbial biomass C content for this profile (Figure 43) and a high C:N ratio. These results confirm the assumption of a possible negative anthropogenic impact on profile 2, based on the higher metabolic coefficient compared with the other soils.

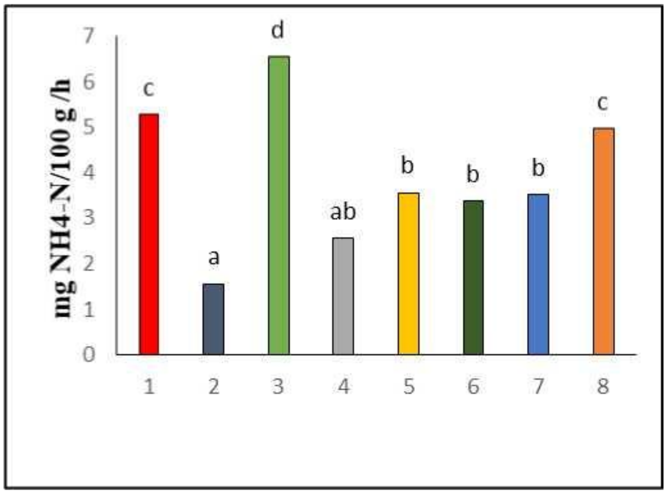


Figure 43. Urease activity of urbanized soils

Legend: 1. Anthropogenically overlapped moderately leached smolnitsa, 2. technogenic soil, moderately deep, 3. *moderately leached Cinnamon forest soil, slightly to moderately eroded, 4. alluvial-meadow soil, moderately deep, 5. alluvial-meadow soil, deep, 6. strongly leached smolnitsa 7. Leached smolnitsa (secondarily carbonated), deep, slightly clayey, 8. Cinnamon forest soil, slightly leached. *(Different letters of the bars show that values differ at level of probability P<0.05)*

Invertase participates in the decomposition of plant residues entering the soil by catalyzing the hydrolysis of sucrose into glucose and fructose. Glucose plays a central role in the biochemical transformation of carbohydrates in soil and serves as an easily accessible energy source for microorganisms. Invertase activity is an important indicator of soil fertility because it is directly related to the presence of easily assimilable carbon compounds by microorganisms. The highest values for invertase activity in the studied soils were obtained for alluvial-meadow soils (profile 4 and profile 5) - 110.47 and 106.91 pg glucose/g/h, respectively, followed by anthropogenically overlapped moderately leached smolnitsa (profile 1) and moderately leached Cinnamon forest soil, slightly to moderately eroded (profile 3). These results are consistent with the data on microbial biomass C content, which was highest in these soils. Significantly lower invertase activity was observed in the technogenic soil of Mladost 3 (profile 2). Profile 7 (leached smolnitsa soil located near a highway) exhibited lower values than anthropogenically overlapped moderately leached smolnitsa (profile 1).

Phosphatases catalyze the degradation of some organic phosphorus compounds (glycerophosphates and sugar phosphates), which represent 30–70% of the total phosphorus reserves in the soil. Because inorganic phosphorus compounds in the soil are characterized by low solubility, it is evident that mobilizing phosphorus from microorganisms is essential for plant nutrition. Sources of soil phosphatases include various tissues and cells of plants, animals, and microorganisms, where they metabolize phosphate. The activity of acid phosphatase in the studied soils ranges from 1.18 to 7.14 pmol, with the highest values being observed in the moderately leached cinnamon forest soil and alluvial-meadow soil. The differences compared with the other soils were statistically significant. Acid phosphatase activity was relatively high in anthropogenically overlapped moderately leached smolnitsa (profile 1) and strongly leached smolnitsa soil (profile 6), with the obtained values being approximately two times higher than those of profiles 7 and 8. Technogenic soil (profile 2) exhibited the lowest phosphatase activity.

The values obtained for invertase and phosphatase activities in the anthropogenically overlapped moderately leached smolnitsa (profile 1) and the two moderately leached smolnitsa soils (profiles 6 and 7) included in the study were relatively close to the values reported by Nedyalkova for untreated soils of the same type in the Sofia Basin.

Peroxidase activity in soil is exhibited by a large number of enzymes that use H2O2 as an electron acceptor during the oxidation of organic and inorganic compounds. Lignin peroxidases, secreted by certain types of bacteria and fungi from the Basidiomycetes and Ascomycetes classes, play an important role in the depolymerization of lignin into secondary metabolites, which are involved in the humification processes of organic substances in the soil. However, high peroxidase activity enhances the mineralization of humic substances and reduces their content in the soil (Mangier & Tate, 1982; Gulko & Khaziev, 1992; Sinsabaugh, 2010). Overall, the release of peroxidases by soil microorganisms is associated with reducing the toxicity of phenolic compounds in the soil, transforming its organic substances, and influencing the activity and composition of soil microbial communities.

In addition to phenolic compounds, peroxidases are also induced with an increase in the Mn content in the soil. Unlike hydrolases, peroxidases are less stable because of their stronger binding to clay minerals in soil. The obtained data show that the studied soils from profiles 1-6 have low peroxidase activity, which varies within narrow limits (0.42 - 0.71 mg purpugallin/1 g soil/h). The lowest peroxidase activity was recorded in moderately leached Cinnamon forest soil, slightly to moderately eroded (profile 3). Higher values compared to the other profiles were obtained for the moderately leached smolnitsa soils (profiles 6 and 7) and the cinnamon forest soil (profile 8). This increase may be due to the inclusion of protective mechanisms related to detoxification of soil pollutants or their intermediate products. For the leached smolnitsa soil (profile 7), an increased Mn content was observed, which may also contribute to the increase in peroxidase activity.

The presented data show that the studied urban soils differed in their enzymatic activities. In general, the moderately leached smolnitsa soil, the leached cinnamon forest soil, and the alluvial-meadow soil (profile 5) were characterized by the highest activity. Anthropogenic soil exhibited the lowest urease, phosphatase, and invertase activity. Low microbial biomass carbon content and enzymatic activity are indicators of potential negative anthropogenic impacts on the microbial populations in this soil. Owing to the strong fragmentation of fill materials and the presence of a large number of artifacts, an unfavorable environment for the progression of biochemical processes is created.

The dependencies of enzymatic activity, CO_2 production, and microbial biomass carbon on some key chemical indicators of urbanized soils were studied through correlation analysis. From the data obtained, it can be seen that organic carbon was positively correlated with urease activity (r = 0.67). This result is consistent with the findings reported by Shi in 2008, who also established a similar relationship between these indicators in urban soils from Shenzhen, South China, as well as with the data reported by Chakrabarti in 2004 for agricultural soils. Total nitrogen is in a positively correlated with microbial biomass carbon (r = 0.82) and phosphatase activity (r = 0.72). Several scientists have also found a positive correlation between the total nitrogen content and some enzymatic activities (including phosphatase) in soils with different land use types (urban, forest, cultivated lands, and pastures). A proven negative correlation was obtained between the C:N ratio and microbial biomass carbon (r = -0.82). This result is logical because with a high C:N ratio and a lack of nitrogen sources necessary for the development of microorganisms, their metabolic processes are delayed, and the amount of microbial biomass decreases. The C:N ratio was negatively correlated with the invertase activity. CO_2 production was positively correlated with the amount of mineral nitrogen (r = 0.76). Soil solution pH was negatively correlated with phosphatase activity (r = -0.78).

Among the studied biological indicators, a proven positive correlation was obtained between CO_2 production and microbial biomass carbon (r = 0.70). This shows that the studied soils are not subject to negative anthropogenic impacts because under stressful conditions, nutrient sources are used inefficiently by soil microorganisms, resulting in less microbial biomass synthesis and increased CO_2 production. Under these conditions, there was no positive correlation between these two indicators.

No proven dependencies were obtained between heavy metal content and CO_2 production, enzymatic activity, and microbial biomass. With the exception of Pb in two of the profiles, the detected heavy metal content in all the studied soils was lower than the precautionary concentrations adopted for Bulgaria. Statistical analysis showed that, under these conditions, there was no risk of disrupting the ecological balance of the soil ecosystem. For the technogenic soil (profile 2) and the alluvial-meadow soil (profile 4), a Pb content close to the precautionary concentrations was detected, but for both soils, no relationship was established between the values of enzymatic activity, CO_2 production, microbial biomass carbon, and the Pb content in the soils.

Conclusions

The results obtained from chemical, physicochemical, agrochemical, radiochemical, morphogenetic, and biological studies of urbanized soils from various urban areas can be summarized as follows:

Urbanization primarily alters the morphological structure of soils and can lead to the formation of new soil types. The new soils resulted from the overlaying of existing soils with earth masses enriched with artifacts and stones of different origins. The overlaying horizons have varying depths, leading to the formation of soils with partially urbanized altered soil profiles or entirely new urbanized profiles. With weak anthropogenic interference, soils have well-preserved horizons with an undisturbed sequence, low rock content, and compaction.

The covered soils were well structured and mainly moderately to highly humus A-horizons with an average depth.

All soils had a moderately high sorption capacity and non-toxic levels of heavy metals (Cr, Zn, Mn, Pb, Cu, Ni, and Co).

The content of radioactive elements in all investigated soils was lower (^{238}U, ^{226}Ra, and ^{232}Th) or close to the background values for the country (^{137}Cs and ^{40}K).

The population and environmental dose load due to natural gamma radiation (emitted by radioactive elements ^{232}Th, ^{226}Ra, and ^{40}K) are two to three times lower than the permissible levels reflected in the external hazard index and the radium equivalent.

The content of the technogenic Pb isotope, generated from sources such as coal combustion for heating and transport by air currents ($^{210}Pb_{ex}$), is higher in the soils of the southeastern part of Sofia than in the northwestern part and does not follow the distribution curve of technogenic cesium.

Macronutrients with significant biological importance (available nitrogen, phosphorus, and potassium) had varying contents in the studied soils, creating an unbalanced environment.

The ferromagnesian biogenic elements, Mn, Zn, Cu, Ni, and Co, were low.

All profiles, except profile 2, were moderately to highly enriched in nitrogen in humus, with a C:N ratio between 9 and 15, indicating a faster humus decomposition process. The humus content in the surface horizons varied between 1.93% (trench 1) and 3.05% (profile 4), reaching up to 5.52% in profile 1, which was relatively optimal.

The studied soils were characterized by a high population of the main groups of microorganisms in the surface soil horizon, which decreased with depth in the soil profile. Bacteria had the highest population density, followed by actinomycetes, while microscopic fungi had the lowest population density. Urbanized soils differ in the relative proportion of these main groups of microorganisms as well as in the dynamics and intensity of mineralization processes associated with the decomposition of organic matter.

The production of CO_2 and the amount of microbial biomass C in the studied soils vary widely (from 4.95 to 18.99 mg CO_2/100 g soil/24 h) and correspondingly (from 14.25 to 46.28 mg C/100 g dry soil). A positive correlation was observed between the microbial biomass C and total nitrogen content.

The activities of urease, invertase, and acid phosphatase in urbanized soils, except for the technogenic soil (profile 2), were relatively high. The strong fragmentation of landfill materials in this soil and the presence of a large number of artifacts create an unfavorable environment for biochemical processes.

Scientific and Scientific-Practical Contributions

As a result of research conducted on urbanized soils from previously unexplored areas, new information has been obtained regarding the structure and composition of urban soils, their physicochemical and chemical status, geochemical characteristics, radioactivity, and biological features.

The content of the radioisotope ^{210}Pb in urbanized soils was determined for the first time in Bulgaria. It has been established that in urban areas, this element has both natural and technogenic origins (^{210}Pbex). The information obtained lays the foundation for comparisons in future scientific research in this direction.

Based on microbiological and enzymatic characteristics, it has been found that in almost all urbanized soils, the activity of the soil microflora is not limited to the anthropogenic environment, which is a good precondition for the functioning of soil ecosystems.

Some soil-forming processes were observed in the studied soils, including the accumulation of soil organic matter, leaching, and secondary carbonation.

The data obtained from this dissertation work enrich the knowledge about soils in Bulgaria, particularly in the region of Sofia. These can potentially be applied to update soil maps, which could be beneficial for planning agricultural activities and determining suitable urban planning and construction methods. This data can be used in the fields of agriculture, environmental science, and nature conservation, both for updating existing databases and as a foundation for new scientific research and projects.

PUBLICATIONS RELATED TO THE DISSERTATION

Tsolova, V., and Tomov, P. 2018. Morphological and Classification Hallmarks of Soils in Green Zones of Sofia. Soil Science, Agrochemistry, and Ecology, 52(3), 43-56. [In Bulgarian]

Petkova, G., Tomov, P., & Tsolova, V. 2019. Microbiological Characteristics of Urban Soils in Sofia city, Bulgaria. Journal of Balkan Ecology, 21(1), 61-70.

Tsolova, V., Tomov, P., Nikova, I., Petkova, G., 2019. Pedo-chemical Perturbations in Soils from Green Ecosystems of the Sofia City (Bulgaria). Ecologia Balkanica 11(2), 37-51.