Urban Soil's Functions: Monitoring, Assessment, and Management

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Abstract

Urbanization is a key trend of current land-use change, responsible for large environmental changes worldwide. Sustainable functioning of urban ecosystems is a priority goal of today and nearest future. Urban soil is a key component of urban ecosystems. Urban soils are formed and exist under predominant direct and indirect effect of anthropogenic factor. Urbanization was traditionally related to negative impacts on soils, whereas the capacity of urban soils to perform environmental functions is poorly understood. Traditional approaches to assess and standardize soil quality through static parameters and health

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thresholds give limited information on soil living phase and its dynamics. Quantifying urban soils' functions directly relates soil quality to the role of soil for environment and society, that is especially relevant in urban ecosystems. This chapter aims to overview existing approaches to monitor and assess soil functions for a specific case of urban soils. Individual functions (i.e., gas exchange and carbon sequestration, bioresources, remediation, etc.) are observed over variety of bioclimatic conditions and for different levels of anthropogenic disturbance. Assessment results are further implemented to develop guidelines and best management practices to construct and treat urban soils for maintaining their functions and quality.

Keywords
Urbanization • Technosols • Soil organic carbon • CO_2 emissions • Heavy metals • Remediation • Soil constructions • Moscow

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18.1 Introduction

Urban ecosystem is a relatively new ecological phenomenon. The first archeological settlements, recognized as towns, date back to 8–10,000 years ago. The first megapolis with the population over one million—the city of Rome—achieved this threshold in the first century BC during the Julius Cesar reign (Denisov et al. 2008). Only 16 cities in the world exceeded one million citizens by 1900. However, this number rapidly increased to more than 400 at the beginning of the twenty-first century (Berry 2008). Urban ecosystems are the most artificial compared to agricultural and natural systems. They are driven by humans and for humans and anthropogenic factors have a predominant influence on such urban environments.

Although urbanization is the most rapid current land-use change trend, urban soil's quality and functions still lack attention. Historically urban soils were ignored by major soil surveys and major conventional soil classifications didn't pay attention to urban soils. Intensive anthropogenic load on soils highlighted attention to soil's health and sanitary quality. Urban soils then were presented as possessing low fertility and exposed to severe disturbances. The most recent concepts of "sustainable cities" focus on urban soil's potential to provide functions and support services, important for humans and environment. Currently, urban soils face a paradox of being of the highest value regarding property and building issue, and being almost totally ignored with regard to the functions and ecosystem services they can provide (Morel et al. 2014). The potential of urban soils to play a key role in an ecosystem of a sustainable city is still poorly studied and rarely used.

In this chapter we aggregated existing knowledge on practices in monitoring, assessing, and managing urban soil's functions. Specific conditions of urban soil's formation and functioning are discussed in Sect. 18.2. Different approaches to identify and classify urban soils and the provided functions are presented in context of highly heterogeneous urban environment (Sect. 18.2.2). Alternative views on urban soil's quality and possibilities to assess it based on urban soil's functions are given in Sect. 18.2.3. The methodology to monitor and assess urban soil's functions is reviewed in Sect. 18.3.1. Different parameters and approaches including resources' assessment, monitoring gas exchange and carbon sequestration, and analyzing soil microbiological activity are discussed. Sections 18.3.2–18.3.4 present assessments of urban soils' functions in different bioclimatic conditions and scales, including monitoring and assessment of urban soils' regimes in Moscow, environmental and economical assessment of soil functions in the Moscow Region. Finally, possible implementations of the assessment results for urban soils' management are discussed in Sect. 18.4, ranging from the straightforward guidelines to manage contaminated soils (Sect. 18.4.2) to more advances automatic intellectual systems and models to optimize urban soil construction (Sects. 18.4.3–18.4.4).

18.2 Soils and Their Functions in Urban Ecosystems

18.2.1 An Overview of Soil Functions' Concept

Soil is a key ecosystems component, playing an important role for environment and human wellbeing (Dobrovolskii and Nikitin 1990; Dobrovolskii and Nikitin 2012; Kazeev et al. 2003; Blum 2005). Soil is vulnerable to environmental risks and threats, such as erosion, decline in fertility and biodiversity, sealing, contamination, and compaction. Monitoring and assessing soil quality at the multiple scales and for different land-uses is among the most essential directions in applied soil science and ecology. Several approaches to distinguish and assess soil quality are known. Historical attitude to soil as an agricultural resource related soil quality to the parameters of soil fertility: organic matter and nutrient content, soil acidity, and texture (Ali 2003; Mairura et al. 2007). Assessment of these agricultural parameters and integral agricultural indexes considered harvested biomass as the primary indicator of soil quality (Karmanov et al. 2002; Bastida et al. 2008). Intensive industrialization and urbanization of the last century resulted in increased anthropogenic pressures on soil, including chemical and biological contamination (Abrahams 2002; Kurbatova et al. 2004). Arisen risk for human health from interaction with contaminated soils highlighted importance of sanitary-hygienic soil quality, assessed through comparison of soil contaminants' concentrations to different standards and health thresholds (CP-11-102-97 1997, MD-2.1.7.730-99 1999). Global environmental problems, including climate change, desertification, soil degrading, and biodiversity depletion, emerged in scientific and political agendas last decades (IPCC 2001; Kazeev et al. 2003) shifted tradition attitude to soil quality towards its role in global biogeochemical processes and provisioning services, like carbon sequestration or genetic reservoir (Swift 2011; Janzen 2004; Blum 2005). Soil quality therefore was related to its functions, rather than to individual features (Karlen et al. 1997).

The term «soil function» or more precisely «soil ecological (environmental) function» was introduced to research and political debates in 1970s to highlight soil's contribution to environment and biosphere (Kovda 1973, 1975, 1981). Primarily distinguished soil functions were rather general and referred mainly to the global scale (i.e., «support for life on the Earth» or «linkage between biological and geological cycles») (Kovda and Rozanov 1988). Impetuous increase of researches in this sphere in the beginning of the twenty-first century resulted in more concrete definitions and more detailed classifications.

Two alternative approaches to define soil functions were developed in Russia (USSR) and US and EU countries. In Russia soil function was defined as a role of soil and soil processes in ecosystems, their preservation and evolution (Dobrovolskii and Nikitin 2012). In contrast, more practical and human-oriented understanding of soil function as an impact of soil processes on the environment and human wellbeing is widely accepted in EU and US research communities (Nortcliff 2002). The purposes of soil functions' implementation also differ between the countries and research schools. For example, analyzing soil functions in land evaluation and land-use planning is among the most essential soil science practices in Germany, UK, and USA (Karlen et al. 2001; Vrscaj et al. 2008), whereas in Russia and post-soviet countries soil functions' concept is more likely used for the purposes of nature conservation, including developing the Red Book of Russian soils (Dobrovolskii et al. 2001; Aparin 2007; Dobrovolskii and Nikitin 2009).

Obtained differences in Russian and international approaches get more evident when analyzing soil functions' classifications. Russian classification includes global and biogeocoenotic functions (Dobrovolskii and Nikitin 2012) and focuses on the multiple-scale interactions between soil and environment. Different European and American classifications propose functions, usually subdivided to ecological and non-ecological (Blum 2005) or natural and useful for man (BBodSchG 1998) with especial attention to soil–human interaction. Different classifications are usually in good coherence regarding the main distinguished functions, however, some divergence occurs (Table 18.1).

Although classification and diagnostics of soil functions was thoroughly studied, much less is known on the methodologies and parameters to quantify soil functions, which constrains implementing the concept in practice (Brown 2003; Vrscaj et al. 2008; Vasenev et al. 2012). Results of soil functions' monitoring and assessment available from literature usually consider a limited number of individual functions, rather than an integral assessment of soil functioning (Kaye et al. 2005; Ananyeva et al. 2008; Smagin 2012). Major assessments of soil functions are focused on natural and agricultural areas, whereas urban ecosystems remain under-observed (Kurbatova et al. 2004; Bond-Lamberty and Thomson 2010; Vasenev et al. 2014a). This chapter aims to review existing approaches to monitor and assess urban soils' function and to illustrate their implementation for environmental assessment, standardization, and soil management practices.

18.2.2 Urban Soils: Formation and Classification

Urban soils are traditionally assumed as exposed to intensive anthropogenic disturbance through sealing, over compaction, pollution, and salinization (Burghardt 1994; Stroganova et al. 1998; Craul 1992). However, this direct anthropogenic influence on urban soils is further complicated by indirect influences of urban environment, altering soil forming factors and soil functioning (Prokofieva and Stroganova 2004; Pickett et al. 2011; Vasenev et al. 2013a). Urbanization processes result in irreversible alternations in former natural and agricultural landscapes. Resulted urban ecosystems are very different from natural analogues in terms of matter and energy fluxes, vegetation, and soils.

Urban microclimate is very different from one in suburban and natural areas. Smoke and dustiness of urban air decrease total amount of solar radiation and the duration of sun shining period, whereas fogs and cloudiness get more likely. Increased annual precipitation is typical for urban climate. For example, annual precipitation in Moscow city is 25% above the regional standard. Mean air temperature in densely urbanized areas is likely higher and spring/autumn frosts are shorter

Table 18.1 Selected soil functions in different classifications[a]

Blum (2005)	Nortcliff (2002)	Ritz et al. (2009)	BBodSchG (1998)	Andrews et al. (2004)	Dobrovolskii and Nikitin (2012)
Biomass production Participating in biogeochemical cycles, including gas exchange between soil and atmosphere Source of raw materials	Provision of physical, chemical, and biological settings for living organisms Supporting biological activity and diversity for plant growth Filtering, buffering, degrading organic and inorganic substances	Food and fiber production Environmental interactions, including carbon retention Supporting habitats and biodiversity	Participation in water and nutrient cycles Decomposition Basis for life of people, plants, animals, and soil organisms Land for agriculture and silviculture An archive of natural and cultural history	Nutrient cycling Biodiversity and habitat Resistance and resilience	Influence on the gas content Storage of nutrients Habitat for terrestrial organisms Source for minerals' and fossils' formation Transformation and transfer of sun energy to the earth bowels Storage of historical artifacts

[a] We used the original names of the functions, given by the authors of each classification

compared to natural conditions. This effect, often thoroughly described in literature since 19th as the "urban heat island" was shown for some megalopolises and even for small settlements. "Urban heat island" affects the air temperature of the 100–300 m layers above the surface and the temperature increase can surpass several degrees (Landsberg 1981; Oke 1973, 1987). Alteration in air and soil temperature influences urban vegetation, providing better conditions for heat-loving species.

Urban vegetation includes both native and introduces species. The latter ones are more sustainable to urban conditions and therefore spread through substantial extents in settlements with different bioclimatic conditions. Urban lawns can occupy up to 40% of the non-sealed urban areas and are more influenced by urban management than by climatic conditions (Milesi and Running 2005; Vasenev et al. 2014a). It results in biotic homogenizing of urban areas located in different climatic zones and adds to the "intrazonal" features of urban landscapes (Müller et al. 2013). Ornamental trees and shrubs, lawns, and flower-beds require specific soil conditions and therefore receive specific soil management like fertilization and irrigation (Vasenev et al. 2015).

Relief and parent materials are another soil forming factors, exposed to irreversible alteration in urban conditions. Urban relief is predominantly artificial. Most of the natural hollows and gullies are filled in and hills are leveled to provide the basis for building construction, landscape, and architectural development. These transformations alter surface run-off and affect soil water balance. The changes in run-off and infiltration may lead to temporally saturation of the urban soils (Kurbatova et al. 2004; Pickett et al. 2011). Parent materials for urban soils' formation include natural and technogenic sediments, cultural layers, and even buried horizons of natural soils (Osipov and Medvedev 1997). These parent materials have a very diverse chemical composition including toxic substances, sewage, industrial and domestic wastes (Prokof'eva et al. 2007). Dust deposition is another important factor, influencing parent materials of urban soils and contributing to the vertical growth of the sediments layers. Urban dust includes soil, rock, and technogenic particles. The role of each component is determined by natural lithological conditions and local sources of air pollution (Miyamoto et al. 2003; Plyaskina 2007; Da Costa Duarte and Oliveira Duarte 2009). Chemical composition of the urban dust depends on the anthropogenic pressure and dominating industries (Yazikov et al. 2004). Dust deposition affects urban soils' features through, for example, increasing carbon, calcium, magnesium, sulfur, chlorine, and heavy metals content (Plyaskina 2007; Prokof'eva et al. 2015). After deposition, dust particles mix with urban topsoil by mesofauna and are affected by soil fungi.

Temporal dynamic of urban soils is also very specific. Permanent anthropogenic disturbances of urban relief and formation of anthropogenic sediments result in short cycles of soils' formation and "young" age of urban soils. Moreover, different susceptibility of urban soil layers to anthropogenic disturbances result in different ages of urban soils' horizons. Dust sedimentation and greenery contributes to the vertical growth of soil layers. This trend of topsoil' vertical growing is referred as "synlithogenic" trend in soil forming process. Synlithogenic soil formation is typical for urban soils and, in contrast, is rare for natural soils, where the major soil forming processes usually are directed down the profile (except, for alluvial and volcanic soils) (Dobrovolsky and Urussevskaya 2004). In result, the relative age of urban topsoil is always younger than in subsoil layers.

Indirect anthropogenic influence results in the following typical; features of urban soil formation: (1) vertical growth of topsoil layers and predominantly “synlithogenic” soil formation process; (2) short time periods for soil formation, resulting in the primitive stages of pedogenesis, typical for some (mainly topsoil) horizons; (3) specific chemical features, caused by dust deposition and anthropogenic disturbances and including alkaline pH, contamination with heavy matters and hydrocarbons, increased carbon and phosphorous content; (4) altered physical features, including high bulk density and stoniness; and (5) specific biological community both in terms of biodiversity and total biomass.

Specific factors of urban soil formation and their specific features determine substantial differences between urban and non-urban soils, recognized by regional and international classifications, which distinguish urban soils as an individual taxon. The international soil classification World Reference Base (WRB) for soil resource distinguishes two reference groups for soil exposed to anthropogenic transformation: (1) Anthrosols for the soils, formed by agricultural activity and (2) Technosols for the soils, formed at the primary soil formation stages with a geomembrane or technic hard material and containing significant amount of artifacts (Rossiter 2007). Most of the soil observed in urban areas relate to the Technosols reference group. Urban soil can also be defined by a qualifier “Technic” if the amount of included artifacts is below required 20% to relate it to Technosols. The latest edition of WRB also includes the “Pretic” qualifier for urban soils, formed on the ancient cultural layers, containing increased amount of phosphorous and carbon and few solid inclusions.

The approach to identify urban soils, implemented in WRB, similarly to approaches used in several regional classification systems (Burghardt 2000; Prokofyeva et al. 2011; Prokof’eva et al. 2013) focus on the young age, synlithogenic features of soil formation, and specific features, for example, neutral or slightly alkaline pH, high bulk density and increased concentration of contaminants, plentiful anthropogenic inclusion, and artifacts. Urban soils’ diagnostic is based on the specific diagnostic horizons (i.e., urbic horizon (UR), resulting from long-term urban pedogenesis and forming in parallel with the synlithogenic deposition of parent material; rehabilitation horizon (RAT), including organic substrates of different origin (peat, composts, fertilizers) implemented to rehabilitate damaged lands or reclaim poor mineral substrates; “technogenic” horizon (TCH), including technogenic deposits of different composition and origin). Different urban soils’ groups distinguished by regional classifications can be more detailed than those proposed by WRB. For example, the classification of urban soils proposed for Moscow city include such types and sub-types as “urbanozems,” “replantozems”, “culturozems,” “urbochemozems,” “necrozems,” “constructozems,” and others (Stroganova et al. 1998; Prokof’eva et al. 2014).

18.2.3 Analyzing Soil Functions to Assess Soil Quality

Spatial heterogeneity and complexity of urban soils in terms of their profiles, morphological, chemical and biological features constrains their ecological standardization and makes assessing urban soils' quality challenging. Different approaches to assess and standardize urban soil's quality exist. The most basic methods compare selected soil features to agrochemical standards or health thresholds. The more advanced approaches consider urban soils' functions and provided ecosystem services as the basis for soil quality assessment. The assessments of soil agrochemical quality vary from measuring conventional soil features (i.e., soil organic carbon, pH, nutrients' contents) (quality (Ali 2003; Barrios and Trejo 2003; Mairura et al. 2007) to more advanced integral indexes (i.e., soil ecological index and agroecological index) (Vasenev and Bukreyev 1994; Karmanov et al. 2002; Savich et al. 2003). Intensive industrialization of the twentieth century and resulted technogenic pressures on soils highlighted sanitary indicators of soil quality, based on comparison of soil pollutants' concentrations to the corresponding health thresholds (i.e., maximal permissible concentration (MPC), estimated permissible concentration (EPC), and an integral Zc index) (HS-2.1.7.2041.06 2006; CP-11-102-97 1997). Chemical soil features as soil quality indicators are sometimes criticized for poor correspondence with soil living phase. Soil biological parameters recently got widely accepted, since they strongly link to majority of soil processes and functions and are very sensitive to anthropogenic pressures (Nortcliff 2002; Gil-Sotres et al. 2005; Gavrilenko et al. 2011; Vasenev et al. 2012; Creamer et al. 2014). The outcomes can, for example, include changes in abundance and species composition of soil microorganisms and their activity resulting from increased anthropogenic disturbance (Kolesnokov et al. 2001; Kazeev et al. 2003; Yakovlev and Evdokimova 2011). Biological indicators of soil quality vary from rather simple and straightforward such as microbial biomass carbon (Wardle 1992; Nannipieri et al. 2002; Ananyeva et al. 2008) or microbial respiration (Ananyeva 2003; Castaldi et al. 2004; Vasenev et al. 2012) to more complex indicators of genetic profiles (Ritz et al. 2009).

Soil quality is usually defined as soil's capacity to perform functions (Karlen et al. 1997; Makarov 2003). Analyzing soil functions is widely used to assess soil quality. Parameters of soil functions used to assess soil quality differ by origin (chemical, physical, and biological) (Nortcliff 2002) and by information source (experimental and calculated) (Bastida et al. 2008). Although the parameters are different, most of them shall satisfy the following requirements as reviewed by Doran (2002): (1) direct relation to corresponding soil functions, (2) reflection of the principal soil processes, (3) sensitivity to land-use change, (4) clarity for stakeholders, and (5) cost and labor accessibility. Soils perform different functions simultaneously (Blum 2005). The consequences of anthropogenic influences on different soil functions can also be different. At the same time, an integral assessment combining the individual soil functions is needed for practical application (Brown 2003). The results of integral assessments and assessment of the individual soil functions complement each other but are not interchangeable. Considering variability of soil features and processes, soil functions measured for different land-use types and bioclimatic conditions shall be standardized (Nortcliff 2002). Relating observed soil functions to those of natural ecosystems in the climax state is a widely used standardization approach (Fedoroff 1987; Gil-Sotres et al. 2005). For this purpose, reference natural ecosystems in similar climatic and lithological conditions to investigated ones are identified. Assessments of urban soils' quality based on the performed soil functions are still rare, compared to soils in natural and agricultural areas. This chapter aims to review different approaches to monitor, analyze, and access urban soils' function as a background for sustainable management of urban soils.

18.3 Approaching to Assess and Monitor Urban soil's Functions

18.3.1 Methodology to Assess Urban Soils' Quality and Functions

18.3.1.1 A Resource-Based Approach for Assessing Urban Soils Quality

The major methodologies conventionally used for ecological evaluation of soil have been derived from a research of homogeneous contiguous environments: water and air. The quality of these environments may be objectively assessed by a value of one of the indicators, which can be used to represent the entire object. Soils, within systems of genetic and functional horizons, and lateral spatial variability, require a different methodology. This methodology should include traditional indicators as well as concentrations of certain substances from given locations with integral characteristics. These integral characteristics reflect *stocks of matter* in the entire soil profile per unit area. We propose that such an approach for soil quality evaluation be referred to as a resource approach. This approach describes a specific amount of soil on a specific area and the amount of deposited substances therein. The latter is divided into beneficial substances (nutrients for plants and soil organisms, and structural components) and harmful substances (pollutants and their complexes) (Smagin et al. 2008). These stocks constitute a real soil resource that can be accurately measured (t/ha, kg/m^2), and be accounted and monitored. They can also be reproduced and remediated (removing a certain amount of harmful substances from a defined area). Soil resources can be evaluated economically at a market value of an adequate weight (volume) of clean fertile soil in a normative layer on a specific land area.

Estimating stocks instead of conventional concentrations enables for a more accurate identification of contaminated urban areas as it was reported by Smagin et al. (2008) for Moscow. Implementing the resource-based approach the authors showed that in the center of the city more than half of the studied soils have exceeded thresholds for the main pollutants. Moreover, most of them have exceeded MPC (EPC) not only in topsoil but also in subsurface horizons over 1 m depth. A similar approach for an environmental regulation of urban soils has been applied for conditionally beneficial substances. These substances are based on essential major nutrients (C, N, P, K) that influence soil fertility and plant growth (Smagin et al. 2008).

18.3.1.2 Measuring Gas Exchange and Carbon Sequestration in Urban Soils

Soil plays a key role in the carbon balance and makes a major contribution to carbon stocks and fluxes (Raich et al. 2002; Schulze 2006). Carbon sequestration and gas exchange are recognized as important soil functions (Swift 2011; Lal 2004). Although different approaches to classify and identify soil functions exist as it was shown in Sect. 18.2.1, they all consider carbon stocks and fluxes as important parameters: up to two thirds of the soil functions are directly or indirectly related to soil carbon cycle. The recently emerged concept of ecosystem services (ESs; MA 2003) expands analyzing environmental properties, processes, and functions with human economic benefits (de Groot 1992; Costanza et al. 1997). Although, soil services are considered part of ESs (Breure et al. 2012), soil carbon sequestration and emissions directly or indirectly affect many specific ESs, including soil fertility maintenance, food production, and climate regulation (MA 2003; TEEB 2010). Methodologies to analyze carbons stocks and soil respiration include field and laboratory approaches, both adopted for the specific urban environment.

Field part of soil carbons stocks' assessments includes investigation of soil profiles and sampling from different horizons or depth layers with further analysis in the laboratory conditions. Soil sampling in urban areas is constrained by their specific spatial structure, complicated with functional and historical zoning and soil sealing (Vasenev et al. 2015). For example, soil sealing is among the main direct anthropogenic influences on urban soils. Sealed soils defined as Ekranic Technosols in WRB (Rossiter 2007) are very challenging to analyze, since sampling these soils is very labor consuming and difficult to get approval for. Sampling from the non-sealed urban areas is usually performed by augering with further reconstruction of the profile and collecting samples from different depths. The depth of augering shall consider the subsoil carbons stocks including ones in the "cultural layers" (Dolgikh and Aleksandrovskii 2010; Vasenev et al. 2013b) and at least 100–150 cm is a recommended.

Field methods to analyze soil respiration (Rs) are based on direct in situ measurements, including alkali absorption techniques (Buyanovsky et al. 1986) and a variety of chamber approaches (open-path, closed-path, and dynamic close chambers) (Nakadai et al. 1993; Bekku et al. 1997; Savage and Davidson 2003). The most advanced current approaches use infra-red gas analyzers (IRGA), providing measurements of CO_2 concentrations with a frequency up to 1 Hz or even higher and thus giving an accurate picture of the CO_2 flux. In addition to measuring total carbon fluxes methods are available to distinguish between SOM-derived and root-derived respiration. The most frequently used methods are based on isotopic approaches (Taneva and Gonzalez-Meler 2011), trenching (Bond-Lambert et al. 2011), and field segregation (Leake et al. 2004; Gavrichkova 2010) as it was reviewed by Hanson et al. (2000). Carbon fluxes' measurements are usually taken in parallel to monitoring soil temperature and soil moisture as the key abiotic drivers of soil respiration (Vasenev et al. 2015).

Samples collected in field are prepared for laboratory analysis, including air-drying, sieving, and pulverizing using a mortar (Vorobyova 1998). Some stages are excluded when soil samples for microbiological analysis are prepared (Creamer et al. 2014). Possible set of the laboratory techniques to analyze urban soil's carbon includes general approaches to quantify total carbon content as well as more detailed measurements of the different fractions: organic, water soluble, hot-water, readily oxidizable, and microbial biomass carbon. In comparison to direct field measurements, soil respiration in laboratory conditions is measured indirectly. Indirect methods estimate soil carbon fluxes as a function of proxy variables obtained from, e.g., remote sensing (Guo et al. 2011; Huang et al. 2013) or measurements of soil microbiological activity under standardized conditions. For example, the basal respiration is a relatively easily measured proxy variable, referring to soil microbiological activity measured in standardized conditions. Basal respiration and in situ respiration methods reflect different processes and obtain therefore characterize soil respiration differently. In situ Rs is sensitive to soil temperature and water regimes and especially to physical disturbance, which is a very common condition in urban areas. It better determines an actual CO_2 efflux and temporal variability in Rs. Basal respiration is strongly linked to chemical soil conditions, influencing the soil microbial community (C and N content, pH, contamination, etc.) and thus characterizes the potential CO_2 emission.

18.3.1.3 Analyzing Soil Microbiological Activity to Quantify Urban Soil's Bioresources

The microbial community is an important soil constituent; its characteristics are recommended for inclusion into the assessments of soil quality and functions (Winding et al. 2005; Bastida et al. 2008). The assessment of soil quality should take into account data on the microbial biomass of soils, the rates of soil respiration, and the rates of nitrogen mineralization. The microbial biomass content (microbial biomass carbon) is one of the most commonly used indicators for soil quality assessments in many studies (Trasar-Cepeda et al. 1998; Kang et al. 2005; Erkossa et al. 2007; Zornova et al. 2007). The microbial biomass is an active agent of the plant residues' decomposition and the destruction of xenobiotic substances in soils. It participates in the cycles of important biogenic elements (C, N, P, S) and in the immobilization of heavy metals and contributes to the stabilization of soil structure (Nannipieri et al. 2002). Though the soil microbial biomass carbon constitutes just several percents of the total soil organic carbon content, it can be considered "the eye of the needle through which all organic material that enters the soil must pass" (Jenkinson 1977). According to researchers the soil microbial biomass is a more sensitive to various disturbances than soil organic carbon content (Anderson and Gray 1989; Wardle 1992; Powlson 1994). Soil microbial biomass carbon content is one of the sensitive indicators of environmental changes (Anderson and Domsch

1986, 1989; Jordan et al. 1995; Hargreaves et al. 2003), therefore it is a valuable index for many ecological researches and monitoring programs (Bölter et al. 2002; Winding et al. 2005). The content of soil microbial biomass may be useful to determine critical thresholds for normal (equilibrium) soil functioning (Knoepp et al. 2000; Andrews and Carroll 2001) to monitor soil quality in various regions and on different scales (Karlen et al. 2001; Arshad and Martin 2002). The microbial biomass carbon is a widely used parameter for soil quality assessment (DIN ISO 14240-1 1997).

Respiratory activity of soil microbial community is also widely used as an indicator of soil resistance to external impacts (Bezdicek et al. 1996; Seybold et al. 1999). Soil (microbial) respiration rate is determined by soil CO_2 production or O_2 consumption (ISO 2002a, b). Soil microbial respiration (soil CO_2 production) is a very sensitive index. Soil microbial respiration is influenced by the soil temperature and moisture, soil structure and nutrients content that predetermines its strong variability in field conditions (Pankhurst et al. 1995). Alternatively, the measurement of soil microbial respiration can be carried out in the laboratory (controlled) conditions, which also excludes contribution to the process of plant roots.

There is lack of data on soil microbiological properties in comparative gradient from natural to urban ecosystems at landscape and regional levels (Lorenz and Kandeler 2005, 2006; Vasenev et al. 2012; Zhao et al. 2013). Soil microbial biomass content, respiration, and microbial community structure are often investigated only for the topsoil (≤20 cm) and at a limited amount of sites, mainly, urban parks and green zones (Li et al. 2001; Matei et al. 2006; Papa et al. 2010; Shirokikh et al. 2011), that is not quite representatively in a variety of anthropogenic impact of urban ecosystem.

The information about microbial community functioning of urban ecosystem is rather scarce. Soil microbial biomass and functions (respiration, consumption of organic substrates) in urban soils were thoroughly described, e.g., for the cities of Aberdeen in Scotland (Yuangen et al. 2006), Caserta in Italy (Papa et al. 2010), Beijing in China (Zhao et al. 2013), Kill and Stuttgart in Germany (Beyer et al. 1995; Lorenz and Kandeler 2005). Low enzymatic and antibiotic activity was shown in soils of some Russian cities (Sharkova et al. 2011; Shirokikh et al. 2011; Gorbov and Bezuglova 2013; Shumilova and Kuimova 2013). Remarkable increase (almost triple) of bacterial nano-forms was reported for the urban soils in Moscow compared to natural analogues. Some local studies report urban soil respiration as comparative or higher than in natural soils (Jo and McPherson 1995; Bandaranayake et al. 2003; Vasenev et al. 2012), although opposite evidences are also known (Castaldi et al. 2004; Barajas-Aceves 2005; Nwachukwu and Pulford 2011). Thus, the basic parameters of many international monitoring programs and assessment of soil quality, including urban soils, focus on microbial biomass and microbial respiration rate (Zavarzin 1994; Höper and Kleefisch 2001; Dilly 2001; Bailey et al. 2002; Schouten et al. 2000; Bloem and Breure 2003).

18.3.2 Monitoring and Assessment of Urban Soil's Functioning Regimes in Moscow Megapolis

Most of research on environmental assessment and standardizing of urban soils focus on the soil features related to solid soil components (i.e., texture, mineralogical, and chemical compounds, including contaminants). However, the resource assessment only focused on the stable parameters may not be enough to assess the quality of soil as a very dynamic substrate. Abundant nutrient content and contaminant's concentration below health thresholds do not guarantee optimal performance of the principal soil functions, including remediation, air quality control, and biomass production. These functions are substantially affected by soil regimes, related to dynamic (non-solid) gas and aqueous phases, physical fields and living organisms. Air and water interactions in soil pores, salt concentrations in soil solutions, soil temperature, and moisture have a predominant effect on soil functioning. Standardizing and monitoring soil regimes for the purposes of urban soils' management have the similar relevance to the more conventional soil resource assessment.

18.3.2.1 Automated Monitoring of the Hydrothermic Features

Monitoring traditional hydrothermic features of urban ecosystems (i.e., temperature and air humidity) is usually based on programmed electronic probes DS1921–DS1923 (USA) (Smagin et al. 2006, 2008). These probes allow for measuring meteorological parameters with high accuracy, frequency, and cost efficiency. In comparison to conventional monitoring techniques, requiring for periodical checking and fitting by the operator, the programmed probes enable a fully autonomous monitoring. Soil temperature regime and its effect on urban vegetation can be assessed based on the following gradation scale developed for the Moscow megapolis (Table 18.2). A good example can be given by temperature regimes' monitoring results obtained for the Kurkino district in Moscow (Fig. 18.1). Soil temperature

Table 18.2 Temperature regimes standard for soils and soil constructions (Smagin et al. 2006)

<−2 °C very low soil temperature	The soil is frozen, the biological activity is suppressed, possible death of root systems and soil organisms
–2 to 0 °C low temperature	The soil is frozen or unfrozen moisture possess a high osmotic pressure, poor biological activity of microorganisms, plants suspended animation
0–5 °C cold soil	Thaw, thawing of the soil, germination of seeds and bulbs, activation of micro-flora
5–10 °C moderately cold soil	Warming up of the soil, heat-loving crops germination, activation of soil fauna
10–15 °C moderately warm soil	Optimal heat supply of the soil, moderate biological activity and crop growth
15–20 °C warm soil	Increased heat supply; activation of evaporation and desiccation of the soil, biological activity and growth is driven by soils moisture
>20 °C high soil temperature	Superfluous heat, drought, and possible inhibition of the biological activity of transpiration and photosynthesis

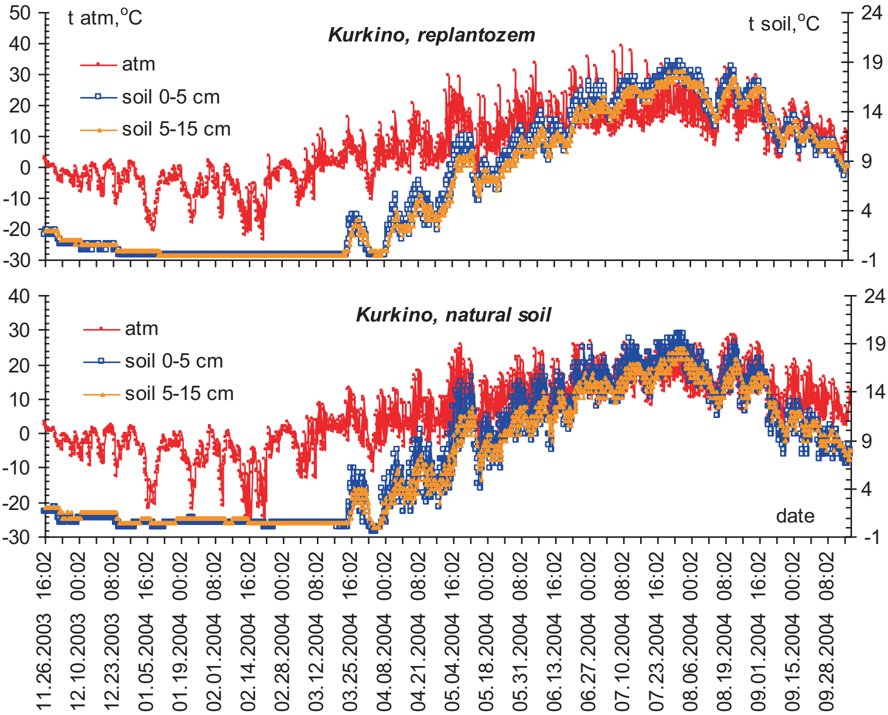


Fig. 18.1 Monitoring results of the urban soils' thermal regime in the residential area of Kurkino district, Moscow

was much more stable than the air temperature during the cold period. Air temperature ranged from values below zero during the thaws to heavy frosts of −20 to 25 °C, whereas soil temperature remained 0–0.5 °C. Different dynamic in soil temperatures was shown for the observed functional zones. Topsoil (5 cm) temperature has never dropped below zero in the recreational zone, dominated by natural soils. Positive temperatures 0.5–1 °C were obtained for the subsoil layers (10–20 cm) in the recreational zone. In contrast, negative −0.5 °C temperatures were obtained for topsoil and subsoil layers starting from late December and early January correspondingly for the disturbed urban soils ("Replantozems"). The negative temperatures for both layers remained till the beginning of April and were not affected by thaws. Lower temperatures in urban soils compared non-disturbed soil is likely resulted from alterations in soil texture and thin (and sometimes lacking) snow cover in urban areas. Long soil frozen periods have a negative influence on urban vegetation, including flowerbeds and green lawns with surface root systems.

18.3.2.2 Monitoring Air-Water Regimes in Urban Soils

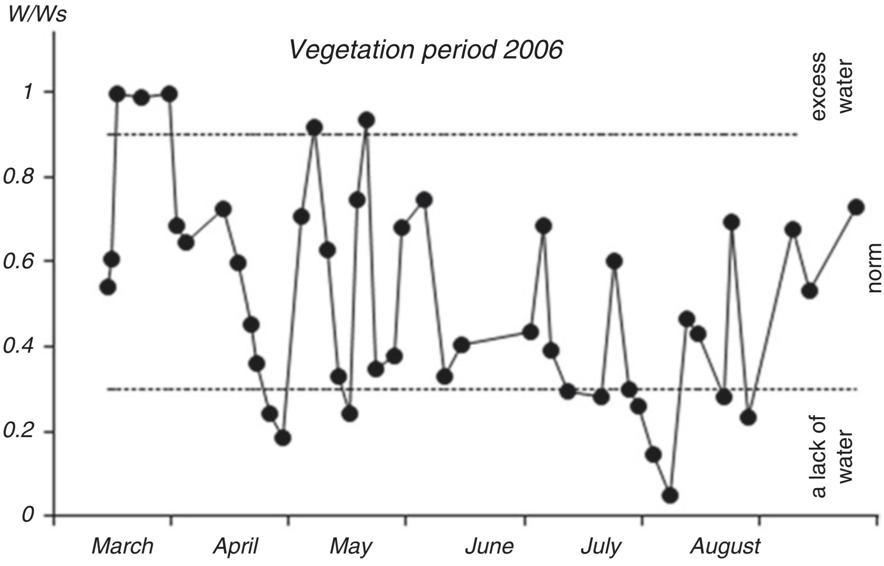
Analyzing air-water regime is critical to monitor urban soils' functions, including supporting urban vegetation, gas emission, biodegradation, and hydrological functions. Soil water scarcity during the draught period or lack of air in pores of

Table 18.3 Standards to quantify air-water regime of urban soils based on W/Ws index (Smagin et al. 2006)

Sands	Loamy sands and peat	Sandy loams, loams	Heavy loams, clays	Comments
>0.8–0.9	>0.85–0.9	>0.85–0.9	>0.85–0.9	High non-productive losses (infiltration, evaporation) grow depression by the lack of air in the soil (over-wetting)
0.2–0.85	0.4–0.85	0.5–0.85	0.6–0.85	Optimal for the plants, but non-productive losses (infiltration, evaporation) of water remain high
0.05–0.3	0.15–0.4	0.3–0.5	0.4–0.6	Available for plants water and low non-productive losses (infiltration, evaporation)
<0.05	<0.15	<0.3	<0.4	Non-available for plants water in the soil

water-logged soil can result in plant's death. Nutrient content and pollution do not have any considerable effect for these extreme conditions. Soil water saturation degree (W/Ws) is a relevant indicator to quantify air-water regime in urban soils. This index is estimated as the ratio of water-containing soil pores to the total soil porosity (water holding capacity) (Smagin et al. 2006; Smagin 2012). The index ranges from 0 to 1 with 0 referring to water scarcity and 1 showing absence of air in soil pores. For the environmental standardization purposes this monitoring index was scaled, regarding dispersity (soil texture) and corresponding water holding capacity of different soils and substrates used for soil construction (Smagin et al. 2006; Smagin 2012) (Table 18.3). The proposed scale is based on the fundamental laws of soil physical state and experiments on thermodynamic assessments of soil water holding capacity (Smagin 2003). The index W/Ws is measured by inductive hydrometers or dielcometers or TDR-reflectors (Decagon, Eijkelkamp equipment). More conventional field gravimetric approaches, based on weighting soil sample of known size, are also relevant (Smagin et al. 2006). The approach was tested for the soils of the Moscow Zoo during the 2 years of observation (Fig. 18.2).

Optimal air-water regime in the root layer was obtained for the major part of the vegetation season 2006. Limited water shortage was found in 10% of observation, whereas 24% of the cases showed over-wetting. The next 2007 year was drier and therefore different trends in air-water regime were monitored: optimal conditions, water scarcity, and over-wetting were obtained in 55%, 38%, and 7% of observations, respectively (Fig. 18.2). Seasonal decrease of soil moisture and water content during the dry period is very typical for urban soils of Moscow (Smagin et al. 2006). This results in unfavorable conditions for flowers and green lawns with maximal root concentration in the surface layers. Degradation of the green lawns during the dry period of the year constrains the aesthetic value of urban areas, increases soil dust hazard, and has a negative influence on urban air quality. Misbalance in carbon cycle resulted from a very low photosynthetic activity at the degraded lawns reduce oxygen production increase carbon emission. Stability of soil cover and prevention of wind erosion (dust events) are also influenced by soil air-water regime.



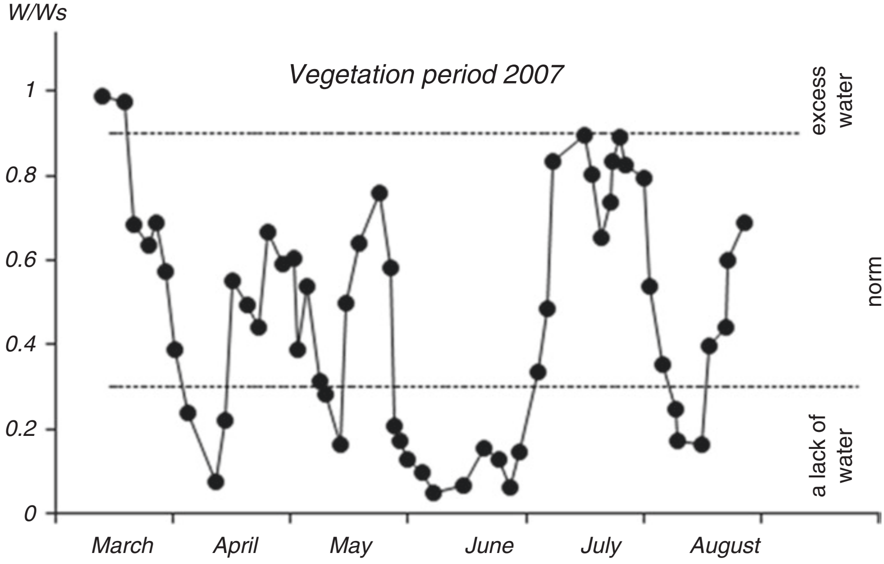


Fig. 18.2 Monitoring results of the urban soils' air-water regime (in the root layer) in the Moscow Zoo (W—soil moisture, Ws—complete water saturation, W/Ws—water saturation rate of pore space)

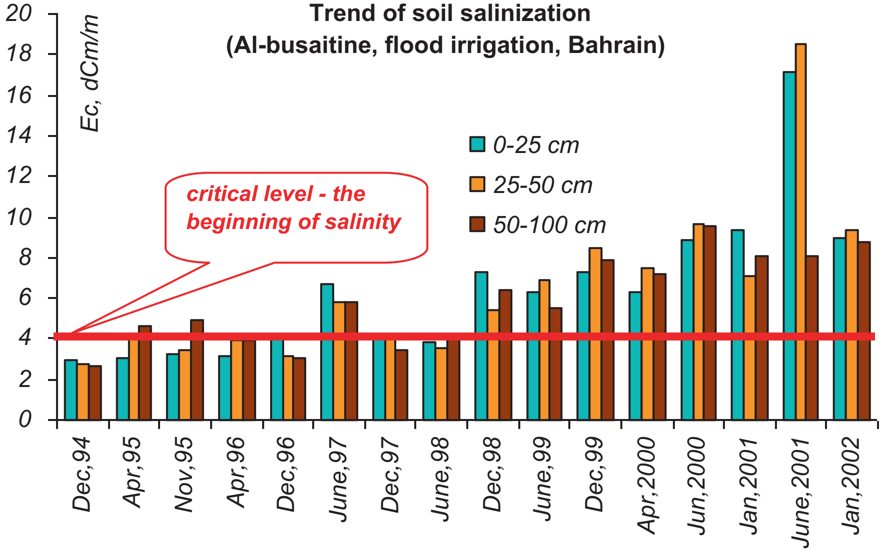
18.3.2.3 Monitoring Salt and Acid-Base Regimes in Urban Soils

Salinization is among the key anthropogenic pressures exposed by urban soils. It is resulted from active usage of "anti-ice" chemical substances and mineral fertilizers in urban management. Electroconductivity (Ec) of the pore solution is a relevant indicator of salinization (Smagin et al. 2006; Smagin 2012). An express assessment of urban soil's salinity and water availability for plants can base on Ec data, measured by portable conductometer-pH-meters (e.g., HI 98130 Combo HANNA). Estimating Ec of saturated pore solution (standard values) is based on measuring Ec for soil suspension in distilled water (usual dilution 1:5), with further multiplication of the results by 500/Ws coefficient (where Ws—is full water capacity). Solution pH is measured in parallel. This method was implemented by Smagin et al. (2006) to compare urban soils in arid and humid conditions as presented (Fig. 18.3). It's interesting that anthropogenic salinization from anti-ice substance in humid conditions of Moscow city can rise Ec up to 20–30 dSm/m, which is similar to the arid landscapes, where soil and water salinization are key environmental problems. Soil salinization, combined with soil and air pollution, caused high mortality of ornamental plants used in greenery works in Moscow in the late 1990s.

A gradual scale standardizing acid-base regime in urban soil is given in Table 18.4. Acid-base regime is monitored based on the pH value measured by conventional potentiometric method and filed or laboratory pH-meters. Acid-base regime of urban soils in Moscow likely deviates from optimal values (Table 18.4) at the central districts and at the roadsides. Accumulation of chemical "anti-ice" substances and building construction dust in urban soils shifts pH to alkaline zone. This depresses urban vegetation and meso- and microfauna of urban soils.

18.3.2.4 Monitoring Biological Activity and Respiration of Urban Soils

Potential biological activity is a very important parameter to assess the effectiveness of soil functioning. This parameter is usually estimated based on the soil respiration measurements in standardized optimal conditions (temperature 25–30 °C; 0.7–0.8 Ws, see detailed methodology for basal respiration (BR) in Sects. 18.4.4 and 18.4.5) (Smagin 2005). These standard conditions were determined based on the previous experiments, analyzing kinetics of biodestruction of soil organic matter in different thermodynamic conditions (Smagin 2005). Analyzing potential soil CO_2 emission (as it described for BR) is widely used to assess soil biological activity. An alternative approach measures oxygen uptake. This method allows eliminating interconnections between soil phases and therefore it is more relevant for mineral soils with low adsorption potential. We developed a gradual standard scale for the urban soils in Moscow city based on this approach (Table 18.5). This scale is implemented to monitor and assess urban soil's function to decompose different organic substrates, including plant residuals, sewage, faces, and domestic wastes. Combination of optimal temperature, air-water, salt and acid-base regimes with low biological activity likely indicates soil chemical or biological pollution. Alternatively, depressed vegetation combined with optimal potential biological activity likely indicates lack of nutrients or limited growing space that is a very often case for urban environment.



with the permission of the Ministry of Agriculture and Municipal Affairs of the Kingdom of Bahrain from (Smagin et al., 2005)

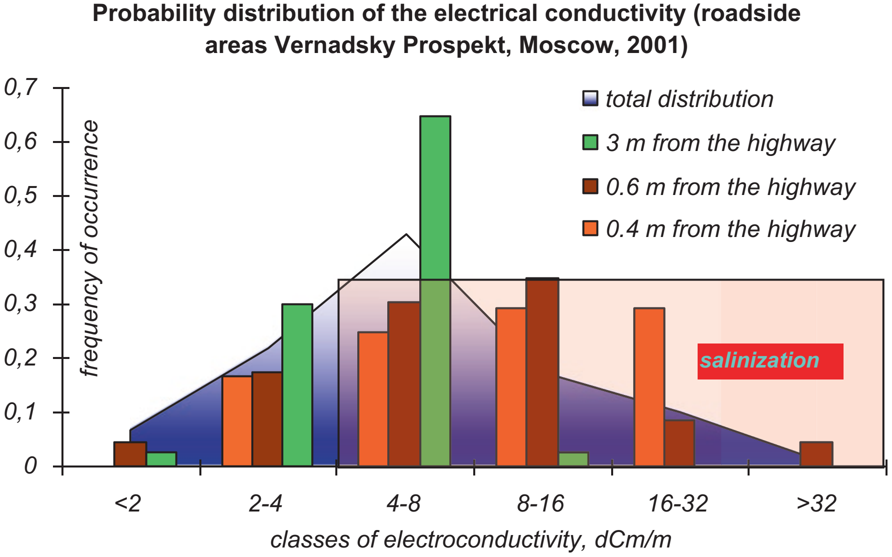


Fig. 18.3 Soil salinity assessed by conductometer (similar problems in the towns in arid and humid conditions)

Table 18.4 Standards to quantify salt and acid-base regimes of urban soils and soil constructions (Smagin et al. 2006)

Ec, dSm/m	Comments	pH	Comments
< 2 salinity is not indicated	Optimal for all plants	<4 very high acidity	Most of plants die; acid destruction of soil minerals (“podzolization”)
2–4 very weak salinity	Only very sensible plants (roses, berries, apples, lilies) may have some damage	4–4.5 high acidity	Cultural plants are depressed; “podzolization” processes in the soil
4–8 weak salinity	Death of sensible species, productivity depression (up to 50%) for most non-tolerated plants; unfavorable physico-chemical alterations in the soil	4.5–5.5 moderate acidity	Optimal for coniferous boreal plants and mosses
8–16 moderate salinity	50–70% productivity depression of tolerated species (palms, cereals, tamarind, casuarinas, oleanders, salt bush, pomegranates, etc.) high degradation of soil	5.5–6.5 weak acidity	Optimal conditions for most plants, including cultural; coniferous and deciduous trees, grasses, and some vegetables
16–32 high salinity	Most of plants die; very high degradation of soil	6.5–7.5 neutral reaction	Optimal conditions for most plants, including cultural; coniferous trees are replaced by deciduous trees and grasses; optimal for most cultural vegetations
>32 very high salinity	Badlands; only very tolerated species (thorn tree, salty plants, sea plants) may live in such conditions	7.5–8.5 alkalinity	Most plants, including cultural have some damage; salinity and degradation of soil
		> 8.5 high alkalinity	High damage and death for most plants; only tolerated vegetation may survive; as a rule high soil degradation and salinity

18.3.3 Assessment of Environmental Functions Provided by Urban Soils in the Moscow Region

18.3.3.1 Introduction

Soil carbon stocks and microbiological activity are assumed to be sensitive and unbiased parameters for the assessment of soil environmental quality (Lorenz and Kandeler 2005; Creamer et al. 2014). Given the strong links between soil quality and functioning (Karlen et al. 1997;), these parameters are also suitable for the assessment of soil functions. This study aimed to assess soil functions in a very heterogeneous and highly urbanized Moscow Region, based on the proposed parameters. The results obtained for the urban soils were standardized by comparison with the natural references (Fedoroff 1987; Gil-Sotres et al. 2005).

Table 18.5 Standardized respiration for urban soils and soil constructions in Moscow (Smagin et al. 2006)

Potential respiration (mg O_2 kg^{-1} h^{-1})	Comments
0–2 very low biological activity	Absence or very low content of organic matter and microbes in soil; biological activity is depressed due to high pollution and salinity; soil is unfavorable for plantation
2–4 low biological activity	Low fertility of soil or (and) its depression by pollution and salinity; plants will be damaged and demand for fertilizing
4–8 moderate biological activity	Normal functioning of soil; optimal condition for most plants, including cultural
>8 high biological activity	High organic matter contents, microbes, and ferments concentration; if plant productivity and decay didn't compensate soil respiration, the soil can be degraded and is a substantial source of greenhouse gases' emission to atmosphere

18.3.3.2 Materials and Methods

The study focused on the Moscow Region, which is an interesting case study to analyze the influence of anthropogenic and bioclimatic factors on soil functions. The urban areas occupy more than 10% of its territory and continue to expand (Kachan et al. 2007). At the same time, the region exhibits a wide range of bioclimatic conditions including soil and vegetation (Shishov and Voinovich 2002). Three contrasting vegetation zones can be identified: south taiga, mixed forests, and forest steppe. Soil variation correlates strongly to these vegetation types with soddy-podzolic (Eutric Podzoluvisols), gray forest soils (Orthic Luvisols), and leached chernozems (Luvic Chernozems), respectively.

The procedure to quantify environmental functions provided by urban soils in Moscow Region included the following steps: (1) sampling of urban and reference natural soils; (2) chemical and microbiological analysis of soil features; (3) quantification of three soil functions through a comparison with reference standard soils of natural ecosystems, and (4) integral assessment of urban soils' functionality. Field data for the assessment of soil functions was collected in Moscow city and in four towns in Moscow Region, representing different bioclimatic conditions, soil types, and settlement history (Table 18.6). In each town three contrasting functional zones were observed: residential, recreational, and industrial. Natural pastures neighboring to the settlements were observed as a standard reference. Both topsoil (0–10 cm) and subsoil (10–150 cm) were analyzed.

The current study focuses on three soil functions: (1) habitat for microorganisms; (2) carbon sequestration; (3) substrate for plant growth. The soil *as a habitat for microorganisms* was assessed on the basis of the microbial carbon (C_{mic}) in comparison with reference standard soil under natural pasture. The C_{mic} was measured in standardized conditions by the substrate-induced respiration approach (Anderson and Domsch 1978; Ananyeva et al. 2008). The ratio between urban and natural C_{mic}

Table 18.6 Characteristics of Moscow city and settlements in Moscow Region

Settlement	Location (N/E)	Area (km^2)	Population (×1000)	Age (years)	Zonal vegetation type	Zonal soil (sub) type
Dubna	56°45′/37°09′	71.6	62.5	<50	South taiga	Peat-podzolic
Voskresensk	55°19′/38°41′	47	104.0	50–200	South taiga	Soddy-podzolic
Pushchino	54°50′/37°37′	17.8	20.0	<50	Mixed and deciduous forest	Gray forest
S. Prudi	54°27′/38°44′	3.7	8.9	200–500	Forest-steppe	Leached chernozems
Moscow	55°45′/37°37′	1097	10,381	50–900	South taiga	Soddy-podzolic

was estimated, expressed in % and graduated into five scores ranging from standard to very low. *Carbon sequestration* was described through carbon stock (soil organic carbon) and microbial respiration, measured in standardized conditions (basal respiration, BR), taken as proxy for the carbon flux. The function was quantified based on the difference of SOC stocks and MR respiration in analyzed and reference soils (see Vasenev 2011 for the detailed of quantification methodology). *The soil as a substrate for plant growth* was assessed using an agroecological index. This logistic function describes the relationship between soil productivity and soil chemical (C_{org}, pH_{KCl}, NO_3^-, NH_4^+, K_2O, P_2O_5, and heavy metals content) and physical properties (soil texture) (see Vasenev and Bukreyev (1994) for the methodological details). Soil standards were taken from the official recommendation on soil quality for green lawns, considering that urban soil cover is dominated by green lawns. All the results were expressed as mean ± standard deviation.

Two approaches were used for the assessment of integral soil functioning: experimental and statistical. An experimental approach assumed the analysis of the integral index $q\mathrm{CO}_2$ (BR/C_{mic}) (Bastida et al. 2008), which is well accepted as an indicator of soil environmental quality (Insam et al. 1996; Vasenev et al. 2013a). High $q\mathrm{CO}_2$ values are interpreted as an indicator of low ecosystem quality, whereas low values refer to optimal state (Insam et al. 1996; Liao et al. 2010). The values $q\mathrm{CO}_2$ of urban soils were compared to reference natural soils and graduated to five scores, same as for the individual functions. The statistical approach was based on the harmonic mean of individual soil functions.

18.3.3.3 Results

Urban soils observed in different bioclimatic conditions of Moscow Region presented large variation, however, the difference between them and reference soils under pastures was significant (Fig. 18.4). Urban soils possessed higher carbon concentrations (especially for the subsoil) and nutrient contents (mainly for the topsoil) than natural ones. Heavy metal concentrations and pH_{KCl} were also higher for the urban environment, whereas microbial respiration and biomass was lower. Statistically significant difference between urban and natural soils in spite of very

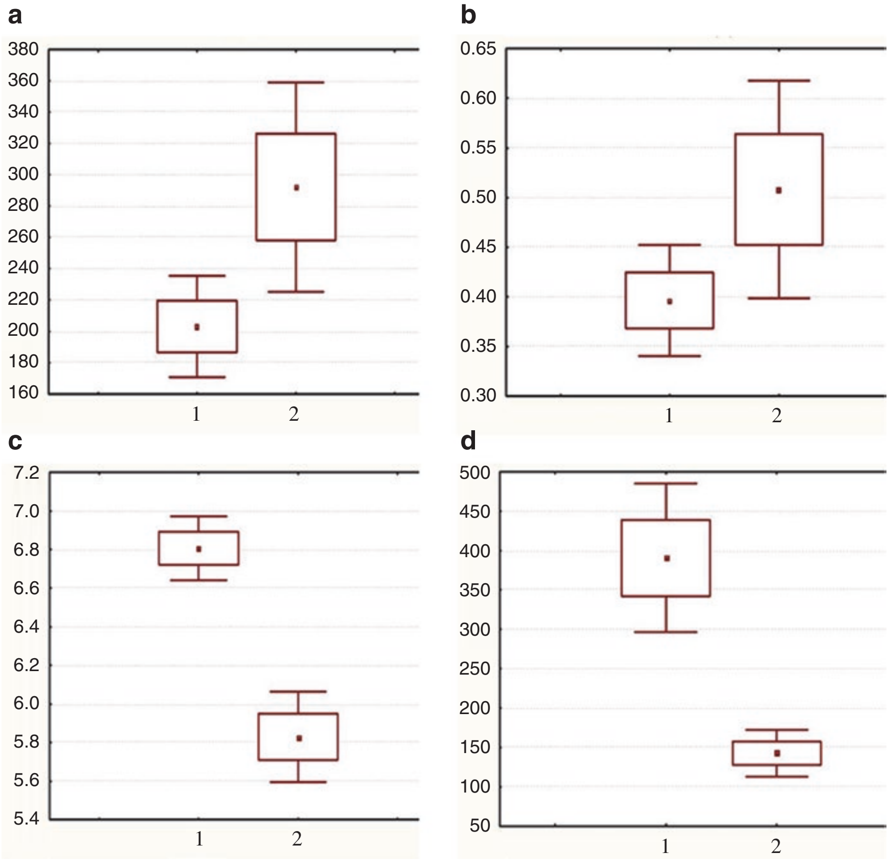


Fig. 18.4 Urban soil features in comparison to reference natural soils: mean, standard deviation and confident interval 95% for Cmic (A), MR (B), pHKCl (C) and P2O5 (D) in urban soils (1) and reference natural soil (2)

high internal heterogeneity is a vivid evidence of urbanization impact on soil features and environmental functions.

Urban soils from different settlements and functional zones inside the settlements were analyzed from the perspective of their environmental functions. Considering high variance between the features of reference soils from different bioclimatic zones, standardization based on reference soils was necessary to obtain results, comparable for different functions and settlements (Table 18.7). Topsoil's "habitat for microorganisms" function in average for the region was assessed as moderate (average score = 2.7; 28% of very low values for the region). The highest values were shown for Pushchino town and the lowest for Dubna settlement (average scores = 5.0 and 1.2 correspondingly). Urban soils in industrial zones performed the function significantly worse than ones in recreational and residential areas. In contrast, for the subsoil standard values of the function performance was reported

Table 18.7 Score scale for assessment of the individual urban functions of urban soils: as a habitat for microorganisms (function 1), carbon sequestration (function 2), substrate supporting plant growth (function 3), and for the integral assessment based on the experimental approach (Int_{qCO_2})

Score	Description	Deviation from the reference	Function 1[a]	Function 2[a]	Function 3[b]	Int_{qCO_2} [a]
5	Standard	No deviation	>95	<105	0.96–1.00	>95
4	High	Slight decline	80–94	105–120	0.75–0.96	80–94
3	Moderate	Intermediate declined	60–79	121–140	0.50–0.75	60–79
2	Low	Strong decline	30–59	141–170	0.25–0.50	30–59
1	Very low	Very strong decline	<29	>171	0.00–0.25	<29

[a] Ratio between the values of urban and reference soil functions (%)
[b] Scale of the agroecological index (Vasenev and Bukreyev 1994)

for 97% of the sampling locations. Performance of the carbon sequestration function in average for the region was assessed as very low for both topsoil (average scores = 2.1, 44% of very low values for the region) and subsoil (average scores = 2.4; 26% of very low values for the region). Soil as a substrate for plant growth was assessed as moderate in average for the region for the case of topsoils (average scores = 2.7; 44% of very low values). For subsoil lower average values were obtained (average score = 1.6 scores; 72% of very low values). The lowest scores were shown for the topsoil of Puschino and Voskresensk, whereas the maximum values were obtained for the subsoil of S. Prudi.

An integral assessment of urban soil's functioning, based on the $q\mathrm{CO}_2$ values, standardized by natural references, was assessed as moderate for the topsoil (average scores = 2.8 scores; 38% of very low values) and low for the subsoil (average score = 1.8; 59% of the very low values). Values shown for urban topsoil in industrial areas were significantly lower than for ones in residential and recreational zones. As an alternative approach for integral assessment of urban soil functionality, harmonized mean of individual assessments was used. In average for the region both topsoil and subsoil functioning was assessed as very low (average score = 1.8 and 2.1 or 59 and 26% of very low values, respectively). The lowest results were shown for the Dubna settlement, the highest were reported for Voskresensk town and Moscow city (Table 18.8). Environmental functioning of urban soils in industrial areas was significantly worse than one in residential and recreational zones.

18.3.3.4 Discussion

The quantification results we obtained may be interpreted differently. On the one hand, in average for the region low and very low functionality was reported and strong negative effect of urbanization on soil environmental functions was demonstrated. On the other hand, high diversity of the values obtained for the individual functions performed by the same urban soils was shown. Thus only for the Dubna town the values for all individual and integral functional assessment were critical.

Table 18.8 The results of environmental assessment of individual functions (soils as a habitat for microorganisms (function 1), carbon sequestration (function 2), substrate supporting plant growth (function 3)), and integral assessment of urban topsoil/subsoil functionality in Moscow Region (based on the experimental (Int_{qCO_2}) and statistical ($\mathrm{Int_{stat}}$) approach)

	Function				
Settlement	1	2	3	Int_{qCO_2}	$\mathrm{Int_{stat}}$
Dubna	1.2 ± 0.4/5.0 ± 0.0	1.0 ± 0.0/1.9 ± 0.6	1.4 ± 1.0/1.0 ± 0.0	1.4 ± 0.7/1.8 ± 1.1	1.0 ± 0.0/1.8 ± 0.4
Moscow	2.9 ± 1.4/4.9 ± 0.8	2.9 ± 1.6/2.1 ± 1.3	2.6 ± 1.6/1.6 ± 1.2	3.0 ± 1.7/2.4 ± 1.6	2.3 ± 1.1/2.0 ± 1.2
Voskresensk	2.4 ± 1.6/4.6 ± 1.3	3.7 ± 1.7/2.2 ± 1.0	3.2 ± 1.8/1.8 ± 1.1	2.8 ± 2.1/1.8 ± 1.0	2.7 ± 1.3/2.2 ± 1.0
Pushchino	5.0 ± 0.0/5.0 ± 0.0	1.9 ± 0.7/3.7 ± 1.1	2.0 ± 1.7/1.0 ± 0.0	4.3 ± 1.3/1.0 ± 0.0	2.0 ± 0.8/2.0 ± 0.0
Serebrianie prudi	2.0 ± 0.9/5.0 ± 0.0	1.0 ± 0.0/2.7 ± 1.2	4.6 ± 1.3/1.6 ± 1.2	2.1 ± 1.1/1.1 ± 0.3	1.7 ± 0.5/3.0 ± 1.1

For other settlements critical values for one individual function were combined with optimal values for the other ones. For example, high quantity of soil microbiota results in optimal values of habitat of microorganisms function. At the same time soil microorganisms are responsible for the predominant part of CO_2 emission by soil, which may refer to decline in carbon sequestration function. Thus the results of integral assessment should be taken into account only considering the values, obtained for the individual functions' assessment. In comparison to traditional approaches for soil quality assessment, where all particular estimates are preliminary result for the final integral one, in case of the functional-environment assessment each individual function value is important

18.3.3.5 Conclusion

An approach for individual and integral quantification implemented in Moscow city and four settlements, located in different bioclimatic zones of Moscow Region, demonstrated high diversity of urban soil's functionality. In average for the region integral assessment results represented low values, however, for the individual functions and locations quantification results were very different and standard performance of one function could go together with low values of the other one by the same soil. Heterogeneity in urban soil's features and functions was mainly the results of different bioclimatic conditions, but also can be taken as the specific characteristic of urban environment. In contrast to many studies (Pouyat et al. 2006; Raciti et al. 2008; Ananyeva et al. 2008) we demonstrated important role of urban subsoil in performance of environmental functions. The values obtained for the subsoil were comparable and sometimes even higher than ones for the topsoil

18.3.4 Analyzing Spatial Variability of Microbiological Activity in Urban and Non-Urban Soils in the Moscow Region for Environmental and Economical Assessment of Soil Quality

18.3.4.1 Introduction

Microbiological processes in soils are very heterogeneous, therefore their spatial variability shall be studied at the different scales (i.e., micro locus, field, landscape, regional, and global) and as effected by different factors (relief, anthropogenic disturbance, and bioclimatic zone) (Bogoev and Gilmanov 1982; Parkin 1993; Zak et al. 1994; Morris and Boerner 1999; Saetre 1999; Yan et al. 2003). Few available studies relate spatial patterns of the microbial soil properties to the position in landscape (Walley et al. 1996), land-use type (Bloem and Breure 2003), season (Ross and Tate 1993), and soil treatment (Morris and Boerner 1999). High sensitivity of the soil microbial biomass content to environmental conditions and anthropogenic disturbances determines this parameter as a robust index to monitor and assess quality and functions of soils under different land-use (Anderson and Domsch 1986, 1989; DIN ISO 14240-1 1997; Winding et al. 2005; Sparling et al. 2004; Benedetti and Dilly 2006). However, spatial variability of microbiological parameters in urban soils is poorly studied, since the methodology and sampling design, relevant for the heterogeneous urban environment is lacking. The estimation of soil's microbiological activity parameters and their spatial variability provide an important background for the environmental and even economical assessment of soil quality.

In the study we developed the methodology to analyze spatial variability of soil microbiological parameters in heterogeneous areas and driving factors behind it (including bioclimatic conditions and soil chemical properties). The methodology was adapted for urban and non-urban soils in two districts of the Moscow Region. The analysis outcomes allowed estimating the microbiological index of soil quality. We compared the estimated microbiological index to the conventional soil ecological index to investigate the performance of both microbiological and agroecological parameters for the purpose of soil quality assessment. Finally, the estimated indexes were used to adjust the economical (cadastral) price of the land, considering the soil quality.

18.3.4.2 Material and Methods

Soil samples were collected in two districts located at the south of the Moscow Region, similar in climatic conditions (mean annual precipitation of 540–600 mm, and the accumulated mean daily temperatures for the growing season is 1800–2100 °C), but different in land-use structure. Agricultural and forest areas dominated in the Serpukhov district, whereas forest and urban areas gave together more than 80% of the Podolsk region. The Serpukhov district is dominated by soddy-podzolic, gray forest, and meadow-alluvial soils (Umbric Albeluvisols, Albic Luvisols, Fluvisols, respectively, according to WRB (2014)), whereas, gray forest soils in Podolsk district are rare. The uniform (grid-based) sampling design was implemented with grid cell of 2 km for Serpukhov and 5 km for Podolsk districts (Fig. 18.5). A topsoil

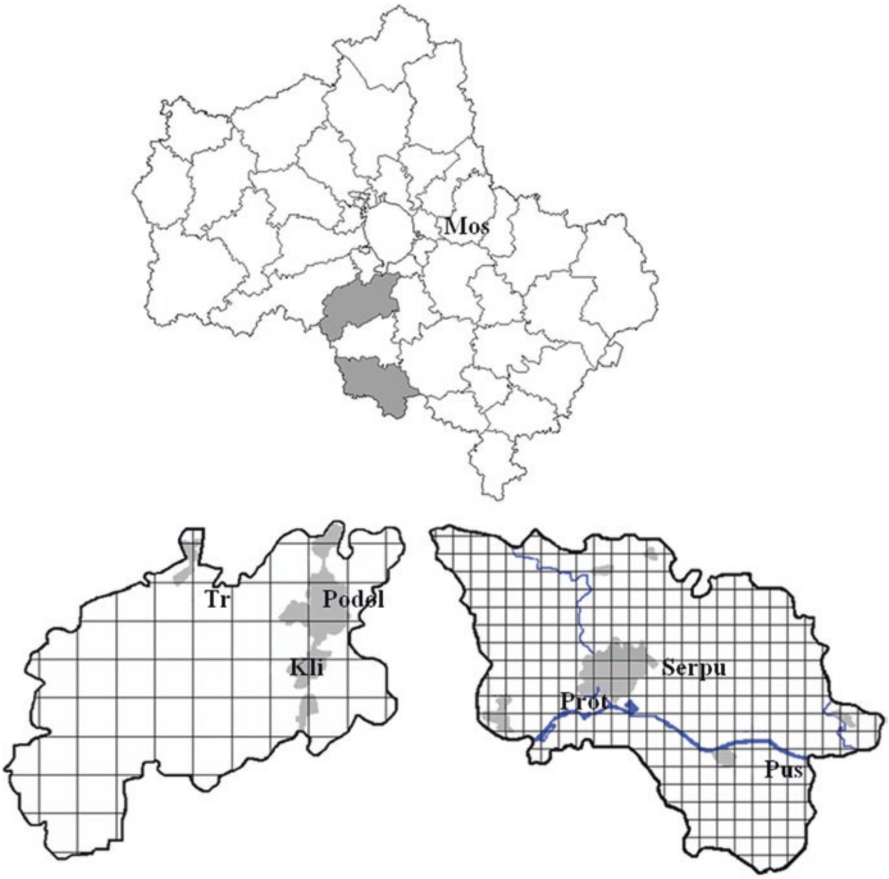


Fig. 18.5 Studied districts of Moscow Region (1—Podolsk, 2—Serpukhov) and soil sampling design

(0–10 cm) mixed sample (center and corners) was taken from the mineral layers at 10 by 10 m plots from each of the grids. Overall, 282 soil samples were taken from three urban (lawn, city park, and industrial area) and three non-urban (forest, fallow and arable) land-use types. Soil samples at natural moistening were kept at 8–10 °C for no longer than 2 months. Before the analyses, the samples were sieved (2-mm mesh) and preincubated.

In the collected samples Corg content was determined by the method of dichromate oxidation (wet combustion); the soil pH was determined in water suspension (soil:water = 1:2.5), and the particle-size distribution analysis was performed by the gravimetric method with the soil pretreatment with sodium pyrophosphate (Arinushkina 1970). The substrate-induced respiration (SIR) and basal respiration (BR) were measured in the samples following the standard methodology (Anderson and Domsch 1978; Ananyeva et al. 2008). *Soil microbial biomass carbon* (C_{mic}) was determined from the SIR data using the following equation: C_{mic} (μg C g^{-1} soil) = SIR (μL CO_2 g^{-1} soil h^{-1}) × 40.04 + 0.37 (Anderson and Domsch 1978). The relative indexes of soil microbial community functioning were calculated: *specific respiration of soil microbial biomass* or microbial metabolic quotient as the ratio of BR to microbial biomass (qCO_2, μg CO_2–C mg^{-1} C_{mic} h^{-1}) and the *portion soil microbial biomass carbon* (C_{mic}) in *soil total organic carbon* (C_{mic}/C_{org}, %). All the measurements were taken in four replicates, mean values ± standard deviations were calculated per dry soil (105 °C, 8 h).

Collected bioclimatic data and measured soil chemical and physical features were used to estimate the soil ecological index (SEI) (Karmanov 1989), comprising physicochemical, agrochemical, and climatic scores. SEI ranges from 0 to 100 with 100 for the highest ecological soil quality (see Savich et al. 2003 and Gavrilenko et al. 2013 for the detailed methodology). The obtained SEI values were used to estimate the soil price as the product of SEI and the tariff category (Rubles ha^{-1}), depending on the land-use type and expected profit from the land-use (Karmanov 1989, 1991). The estimated price was adjusted using a correction coefficient of SEI, considering soil microbial biomass carbon.

18.3.4.3 Results

High spatial variability in chemical and microbiological features, reported for the research districts, was determined by various ecosystems and soil types. For example, the highest C_{mic} and BR values were obtained for the forest, compared to arable and urban areas. The mean C_{mic}/C_{org} values of arable and urban soils were significantly lower compared to forest and fallow. The C_{mic} and BR in meadow-alluvial and urban soils were significantly lower than in soddy-podzolic soils in the Podolsk district. In the Serpukhov district the highest C_{mic} was found in soddy-gley soils, whereas the highest BR was observed in bog-podzolic and soddy-gley soils. Meadow-alluvial and urban soils possessed the lowest C_{mic} and BR (Tables 18.9 and 18.10). The highest qCO_2 was found for forest ecosystems, whereas qCO_2 for the arable soils in Serpukhov district was the lowest. The mean qCO_2 value (averaged for the two districts) under coniferous forests was significantly higher than that under mixed and deciduous forests (2.97; 2.31 and 1.74 μg CO_2–C mg^{-1} C_{mic} h^{-1}, respectively). The lowest significant mean C_{mic}/C_{org} values were observed in the arable and urban soils of studied districts, whereas the highest—in forest and fallow ecosystems (Tables 18.11 and 18.12). Relationships between microbiological activity, soil type, ecosystems, and relief elements have been estimated by the three-way ANOVA. The highest contribution in C_{mic} and BR variance belongs to "ecosystem" factor (50 and 80%, respectively), and the lowest one was shown for the "soil" (30 and 9%, respectively).

Obtained soil chemical and physical features incorporated with the bioclimatic data were standardized and ranked to estimate SEI. The SEI values for the studied soils ranged from 28.4 to 98.5 scores. The average values for the fallow and cropland ecosystems were significantly higher than those for the forest ecosystems (Table 18.13). The most significant variation in the SEI (28.4–82.0) was observed for the forests and fallows (39.2–98.5). In the group with the low SEI (≤50), a

Table 18.9 Soil organic carbon content (C_{org}) and soil pH in different soils (0–10 cm) of Podolsk (P) and Serpukhov (S) districts of Moscow Region (value with different letters significantly differ, $p \leq 0.05$, for each column separately)

Soil[a] (number sites, P/S)	C_{org}, % (range/mean)		Soil pH_w, (range/mean)	
	Podolsk	Serpukhov	Podolsk	Serpukhov
MA (3/24)	0.87–1.25/1.08 *a*	0.50–3.29/1.76 *a*	7.60–7.90/7.72 *b*	6.30–8.05/7.33 *d*
GF (0/56)	Not found	1.04–4.22/2.20 *ab*	Not found	5.37–7.29/6.21 *c*
SP (34/133)	0.96–4.43/2.38 *b*	0.38–5.14/2.49 *ab*	4.43–7.44/5.57 *a*	4.02–7.70/5.30 *b*
U (8/16)	1.10–3.65/2.49 *b*	1.35–10.11/3.23 *b*	6.64–7.85/7.42 *b*	5.91–8.29/7.31 *d*
SG (0/4)	Not found	6.84–9.40/7.72 *c*	Not found	5.64–6.70/6.33 *c*
BP (0/4)	Not found	10.03–27.66/15.29 *d*	Not found	3.70–4.25/4.01 *a*

[a] *MA* meadow-alluvial, *GF* gray forest, *SP* soddy-podzolic, *U* urban, *SG* soddy-gley, *BP* bog-podzolic

Table 18.10 Soil microbial biomass carbon (C_{mic}) and soil basal respiration (BR) of different ecosystems in Podolsk (P) and Serpukhov (S) districts of Moscow Region (value with different letters significantly differ, $p \leq 0.05$, for each column separately)

Ecosystem (number site, P/S)	C_{mic}, μg C g^{-1} (range/mean)		BR, μg CO_2-C g^{-1} soil h^{-1} (range/mean)	
	P	S	P	S
Arable (4/13)	43–318/155 *a*	72–252/150 *a*	0.06–0.74/0.39 *a*	0.06–0.42/0.18 *a*
Urban (8/16)	67–566/274 *a*	47–392/214 *ab*	0.09–0.77/0.38 *a*	0.14–0.56/0.35 *ab*
Fallow (8/82)	166–530/365 *a*	53–883/314 *b*	0.17–0.92/0.61 *a*	0.16–1.12/0.49 *b*
Forest (25/126)	173–1394/637 *b*	58–1366/530 *c*	0.34–3.25/1.15 *b*	0.19–2.43/0.95 *c*

significant part (86%) belongs to forest soils. In the forest soils, the significant lowest SEI was under pine forests, whereas the highest SEI corresponds to the predominance of leaved species. The spatial visualization of SEI for studied region was carried out (Fig. 18.6), which showed larger heterogeneity of SEI in the Serpukhov district (28.4–98.5 scores) compared to the Podolsk (41.7–82.7 scores). The contribution of different factors to SEI variance of studied soils was estimated by the three-way ANOVA. The most significant contribution to SEI total variance was shown for "soil," "ecosystem," and "relief" factors (45, 20, and 17%, respectively). The relationships between the SEI values and the physicochemical and microbiological characteristics of the studied soils were assessed by correlation analysis. The relationships between SEI and the microbiological characteristics (C_{mic}, BR, qCO_2, C_{mic}/C_{org}) were significant for forest soils, urban soils (C_{mic}, qCO_2, C_{mic}/C_{org}), arable (BR, C_{mic}/C_{org}), and fallow soils (C_{mic}, qCO_2). For forest soils, the relationship between SEI and microbiological indices (C_{mic}, C_{mic}/C_{org}, qCO_2) is approximated by the corresponding equations with significant coefficient of determination (Fig. 18.7).

Table 18.11 Soil microbial metabolic quotient ($q\mathrm{CO}_2$, μg CO_2–C mg^{-1} $\mathrm{C}_{\mathrm{mic}}$ h^{-1}) of different soil (0–10 cm) ecosystems, and relief elements in Podolsk (P) and Serpukhov (S) districts (value with different letters significantly differ, $p \leq 0.05$, for each column and each parameter separately)

Number site (P/S/ P + S)	P	S	P + S
Ecosystem			
Arable (4/13/17)	1.46–4.03/2.32 *a*	0.64–1.79/1.14 *a*	0.64–4.03/1.42 *a*
Fallow (8/82/90)	0.99–2.86/1.72 *a*	0.68–3.40/1.76 *b*	0.68–3.40/1.76 *a*
Urban (8/16/24)	1.08–2.37/1.56 *a*	0.90–3.78/1.95 *b*	0.90–3.78/1.82 *ab*
Forest (25/126/151)	1.08–3.14/1.84 *a*	0.34–6.52/2.31 *b*	0.34–6.52/2.23 *b*
Soil[a]			
SG (0/4/4)	Not found	0.34–2.03/1.15 *a*	0.34–2.03/1.15 *a*
MA (3/24/27)	0.99–1.85/1.44 *a*	0.64–3.40/1.41 *a*	0.64–3.40/1.41 *ab*
GF (0/56/56)	Not found	0.60–2.88/1.57 *ab*	0.60–2.88/1.57 *ab*
BP (0/4/4)	Not found	1.33–2.11/1.88 *ab*	1.33–2.11/1.88 *ab*
U (8/16/24)	1.08–2.37/1.56 *a*	0.90–3.78/1.95 *ab*	0.90–3.78/1.82 *ab*
SP (34/133/167)	1.08–4.03/1.91 *a*	0.82–6.52/2.38 *b*	0.82–6.52/2.28 *b*
Relief			
Floodplain (0/21/21)	Not found	0.64–2.95/1.24 *a*	0.64–2.95/1.24 *a*
Upper slope (13/76/89)	1.08–2.16/1.62 *a*	0.82–4.00/1.84 *b*	0.82–4.00/1.81 *b*
Middle slope (15/52/67)	1.20–4.03/2.09 *a*	0.34–5.26/2.09 *b*	0.34–5.26/2.09 *b*
Watershed (12/65/77)	1.08–2.97/1.78 *a*	0.60–5.12/2.14 *b*	0.60–5.12/2.08 *b*
Low slope (5/23/28)	0.99–2.41/1.60 *a*	1.12–6.52/2.96 *c*	0.99–6.52/2.72 *c*

[a] See Table 18.9

The obtained SEI values were used to estimate the soil price in the investigated districts, considering an appropriate tariff category from 1991 (the year when the tariffs were officially fixed for the last time) (Gavrilenko et al. 2011, 2013). The calculated soil price of different studied ecosystems is given in Table 18.14. The price of arable soil was in average significantly ($p \leq 0.05$) higher than that of fallow soil. The soil price under woody stands (forest) was significantly higher than that of grassy (fallow + arable) ones. Therefore one would assume that forest soils should be evaluated higher than those, for example, of arable and fallow lands, since their physical and chemical properties and ecological functions are preferable. The influence of the “forest type” and “soil” on the price of forest soils for studied districts was analyzed by ANOVA. Both factors (“forest type” and “soil”) were significant and determined by 33 and 55% of the total variance, respectively.

SEI characterizes soil physicochemical properties and regional climatic conditions. Soil biological property might be characterized by soil microbial biomass content, expressed as soil microbial biomass carbon ($\mathrm{C}_{\mathrm{mic}}$). A positive significant correlation of SIE with $\mathrm{C}_{\mathrm{org}}$ and $\mathrm{C}_{\mathrm{mic}}/\mathrm{C}_{\mathrm{org}}$ ratio was found for forest soils of the studied region. Therefore, we used a correction coefficient of SEI, considering soil microbial biomass carbon, to assess the soil price for different ecosystems (forest, fallow, arable). The average soils price in the Podolsk and Serpukhov districts of the Moscow Region were almost 18,000, 8500, and 4300 Rubles ha^{-1} (in 1991 year.) for

Table 18.12 Portion of microbial biomass carbon in total soil organic carbon (C_{mic}/C_{org}, %) of different soil (0–10 cm) ecosystems, and relief elements in Podolsk (P) and Serpukhov (S) districts (value with different letters significantly differ, $p \leq 0.05$, for each column and each parameter separately)

Number site (P/S/P + S)	P	S	P + S
Ecosystem			
Urban (8/16/24)	0.42–1.86/1.05 *a*	0.19–1.41/0.77 *a*	0.19–1.86/0.86 *a*
Arable (4/13/17)	0.50–1.89/1.19 *a*	0.55–1.98/1.02 *a*	0.50–1.98/1.06 *a*
Fallow (8/82/90)	1.33–4.03/2.40 *b*	0.32–5.10/1.75 *b*	0.32–5.10/1.81 *b*
Forest (25/126/151)	0.70–3.36/2.39 *b*	0.22–10.65/1.88 *b*	0.22–10.65/1.96 *b*
Soil[a]			
BP (0/4/4)	Not found	0.36–0.59/0.49 *a*	0.36–0.59/0.49 *a*
U (8/16/24)	0.42–1.86/1.05 *a*	0.19–1.41/0.77 *ab*	0.19–1.86/0.86 *ab*
MA (3/24/27)	0.50–1.33/0.83 *a*	0.42–3.11/1.22 *ab*	0.42–3.11/1.17 *ab*
SG (0/4/4)	Not found	1.01–1.86/1.44 *abc*	1.01–1.86/1.44 *abc*
SP (34/133/167)	0.70–4.03/2.39 *b*	0.22–10.65/1.67 *bc*	0.22–10.65/1.82 *bc*
SG (0/56/56)	Not found	0.67–5.72/2.39 *c*	0.67–5.72/2.39 *c*
Relief			
Low slope (5/23/28)	0.42–1.53/0.89 *a*	0.27–3.11/1.05 *a*	0.27–3.11/1.02 *a*
Floodplain (0/21/21)	Not found	0.55–2.49/1.20 *a*	0.55–2.49/1.20 *ab*
Middle slope (15/52/67)	0.58–4.03/2.20 *b*	0.22–4.71/1.46 *ab*	0.22–4.71/1.62 *bc*
Watershed (12/65/77)	0.54–3.20/1.81 *b*	0.19–10.65/1.81 *bc*	0.19–10.65/1.81 *cd*
Upper slope (13/76/89)	1.89–3.15/2.53 *b*	0.37–6.22/2.14 *c*	0.37–6.22/2.20 *d*

[a]See Table 18.9

Table 18.13 Soil ecological index (SEI) of different ecosystems in Serpukhov (S) and Podolsk (P) districts (value with different letters significantly differ, $p \leq 0.05$, for each column separately)

Ecosystem (number sites, P/S/P + S)	SEI, score (range/mean)		
	Podolsk	Serpukhov	P + S
Forest (25/126/151)	54.2–64.6/59.5 *a*	28.4–82.0/53.3 *a*	28.4–82.0/54.4 *a*
Urban (8/16/24)	50.8–82.7/70.3 *b*	43.7–88.7/61.2 *b*	43.7–88.7/64.2 *b*
Fallow (8/82/90)	41.7–81.8/67.2 *ab*	39.2–98.5/70.5 *c*	39.2–98.5/70.2 *bc*
Arable (4/13/17)	58.2–79.3/68.4 *b*	53.3–91.6/74.2 *c*	53.3–91.6/72.8 *c*

forest, fallow, and arable ecosystems, respectively (Fig. 18.8; Table 18.15). The spatial distribution of soil prices calculated basis on SEI, tariff category, correction biological coefficient in the Podolsk and Serpukhov districts of the Moscow Region is shown in Fig. 18.8. Incorporating of the soil biological properties in the soil price estimates enables considering both economical and environmental soil quality.

18.3.4.4 Discussion

Soil microbial biomass carbon is an important characteristic of soil functions (Anderson and Domsch 1989; Wardle 1992; Bölter et al. 2002). It was proved that the microbial biomass is more sensitive to environment changes than the soil organic

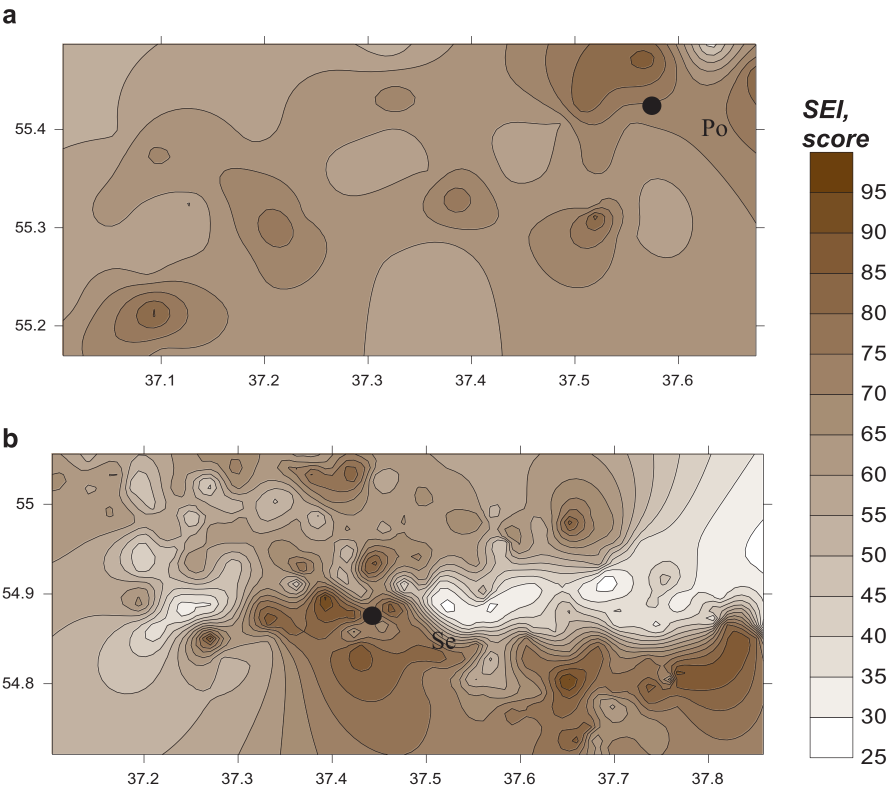


Fig. 18.6 The soil ecological index (SEI) distribution in Podolsk (**a**) and Serpukhov (**b**) districts of Moscow Region (axis X is E°, axis Y is N°)

matter content (Franzluebbers et al. 1995; Hargreaves et al. 2003). In addition, soil microbial biomass is a reliable indicator of crop yields (Jordan et al. 1995). Basal respiration of soil microorganisms indicated an availability of soil organic carbon. Although the microbial respiration at natural (field) conditions is highly variable (Cook and Greaves 1987; Martin and Bolstad 2009), mainly due to changes of hydrothermal conditions, under laboratory conditions (40–60% water holding capacity, 15–25 °C), soil respiration may be accurately and precisely determined. In our study, BR was less "sensitive" to ecological factors than C_{mic}, though there is a close positive correlation between these parameters.

Investigated soil microbiological parameters complemented more conventional physicochemical characteristics for soil quality assessment through the SEI index. The methodology of SEI estimation suggested by Karmanov (1989) was initially designed for agricultural soils and focused on the soil fertility. We expanded the implementation of the index to estimate soil quality for different ecosystems. The higher SEI values obtained for the arable lands compared to the forest areas were likely caused by the main attention given to agrochemical features (i.e., nutrient

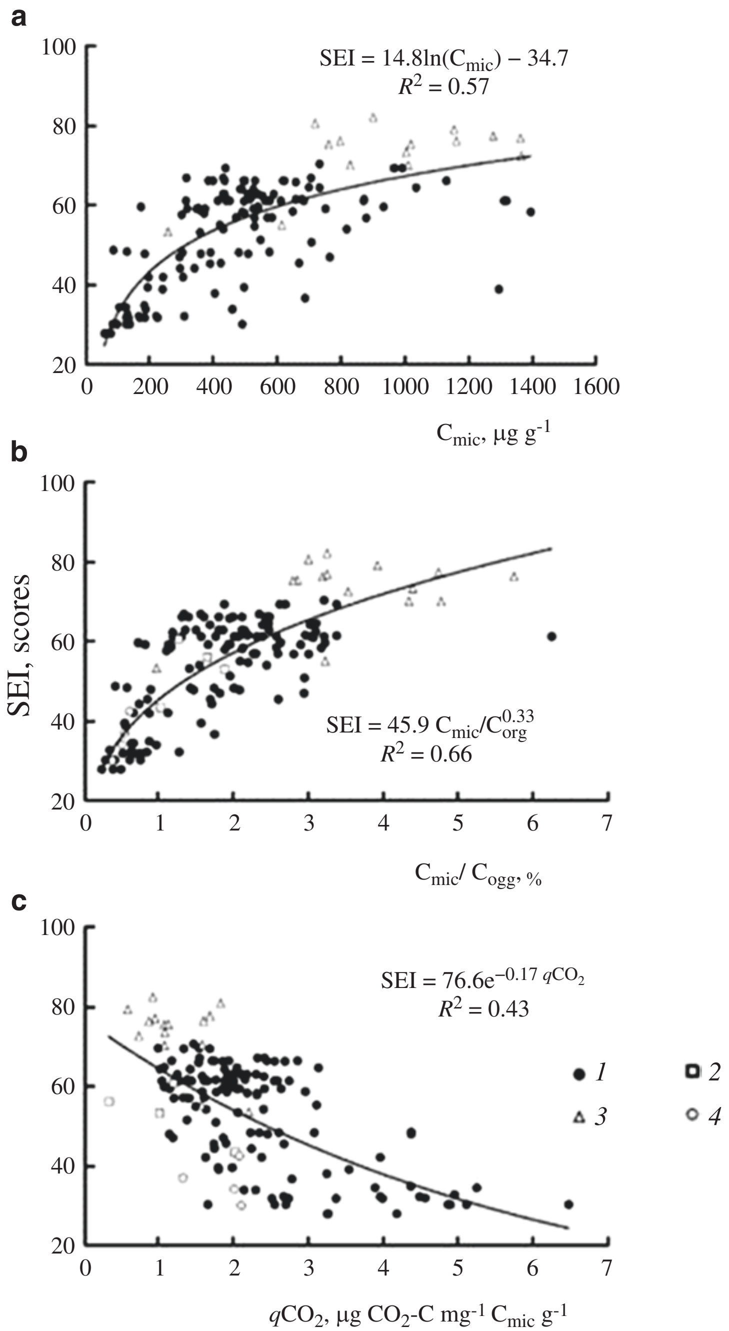


Fig. 18.7 Relationships between soil ecological index (SEI) and soil microbial biomass carbon (C_{mic}, $n = 143$, bog-podzolic and soddy-gley soils are excluded) (**a**), and portion of soil microbial biomass carbon in total organic carbon (C_{mic}/C_{org}, $n = 148$) (**b**), and microbial metabolic quotient ($q\mathrm{CO}_2$, $n = 149$) (**c**) for forest soils of Moscow Region: (1) soddy-podzolic, (2) gray forest, (3) soddy-gley, (4) bog-podzolic

Table 18.14 Soil price (1991 yr.) of different ecosystems in studied Serpukhov and Podolsk districts, calculated on basis of soil ecological index and tariff category (value with different letters significantly differ, $p \leq 0.05$)

Ecosystem (number sites)	Soil price, Rubles ha^{-1} (range/mean)
Forest (151)	9358–27,068/17,935 *b*
Fallow (90)	5494–27,352/12,071 *a*
Arable (17)	8154–25,659/18,469 *b*
Fallow + Arable (107)	5494–27,352/13,087 *a*

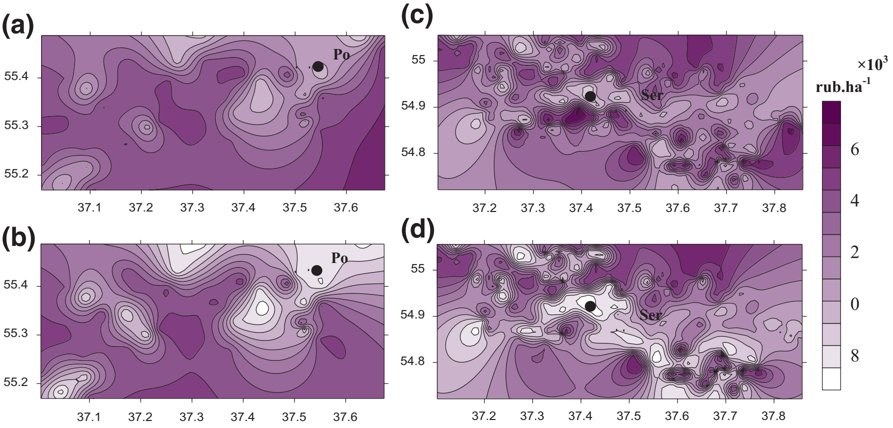


Fig. 18.8 Distribution of soil price in the Podolsk (**a**, **b**) и Serpukhov (**c**, **d**) districts of the Moscow Region calculated by multiplication of soil ecological index and tariff category (**a**, **c**) and by biological correction coefficient (**b**, **d**)

Table 18.15 Soil price (1991 yr.) of different ecosystems in Serpukhov and Podolsk districts calculated on basis of soil ecological index (SEI), correction coefficient (CC, for forest it equal 1), and tariff category (value with different letters significantly differ, $p \leq 0.05$, for SEI and C_{mic} separately)

Ecosystem (number sites)	SEI, score	C_{mic}, μg C g^{-1} soil	CC	SEI* (SEI × CC), score	Tariff category (T)	Price (SEI* × T)
					Rubles ha^{-1}	
Forest (151)	54.4 *a*	548 *c* (I)	1 (I/I)	54.4	330	17,952
Fallow (90)	70.2 *b*	319 *b* (II)	0.58 (II/I)	40.7	210	8551
Arable (17)	72.8 *bc*	152 *a* (III)	0.28 (III/I)	20.4	210	4280

concentration and soil texture) in the estimation of SEI. Considering lower nutrients' supply and acid pH of the forest soils, the SEI values obtained for the forest soils were relatively low. However, taking into account the high ecological significance of forest soils, an underestimation is very likely. To avoid this underestimation we implemented a corrective biological coefficient, based on the close correlation between SEI and soil microbiological characteristics (C_{mic}, C_{mic}/C_{org})

found for different land-use types in the research area. The SEI values in fallow, arable, and urban areas were standardized based on the C_{mic} for the corresponding land-use related to the C_{mic} for the forest taken as a natural reference. For example, C_{mic} averaged for the urban areas in the region was 152 μg C g^{-1}, which was just 43% from the forest C_{mic} (548 μg C g^{-1} soil), giving the correction coefficient 0.43. Therefore, the SEI averaged for the forest, fallow, urban and arable soils calculated with due account for C_{mic} should be equal to 54.4 (54.4 × 1.00), 40.7 (70.2 × 0.58), 27.6 (64.2 × 0.43), and 20.4 (72.8 × 0.28) scores, respectively.

The average SEI obtained for the urban soils were higher than that in forest ecosystems (64 and 54 scores, respectively). It should be taken into account that the most urban soils had the high supply of available nutrients (32.3 mg 100 g^{-1} soil for P_2O_5 and 16.7 mg 100 g^{-1} soil for K_2O) and high pH value (7.3). However, the microbiological parameters (C_{mic}, C_{mic}/C_{org}, BR) of urban soils were significantly lower than those of natural ecosystems (fallow, forest). Thus, the SEI-based ranking (arable > fallow > urban > forest) can be transformed to the other one (forest > fallow > urban > arable) when the correction coefficient was implemented. The new rating of soil quality for different ecosystems considering for their biological properties is more reliable from the ecological point of view.

The same underestimation of the forest soils over croplands was shown for the soil price estimation. Low cadastral prices traditionally given to the forest lands compared to agricultural lands in the result of soil features and functions' ignorance. For example, the cadastral price of the forest land based on wood species productivity ignore soil ecological functions conservation, oxygen production, toxins absorption, water and wind erosion prevention, microclimate regulation, that underestimates the value of the forest soils for environment and society (Shimanuk 1974; Savich et al. 2003; Dobrovolskii and Nikitin 2006; Makarov and Kamanina 2008). Therefore, the proposed approach of cadastral assessment based on the soil ecological index, tariff category, and biological correction coefficient gives a promising tool to consider soil quality and functions in land assessment.

18.3.4.5 Conclusion

Although high spatial variability in soil chemical, physical, and microbiological features was observed, significant difference in soil quality and performed soil functions was found between different land-use types: forest, cropland, and urban. Urban environment was not favorable for soil microorganisms, which was clearly shown by low microbiological activity parameters (C_{mic} and BR) and integral indexes (qCO_2 and C_{mic}/C_{org}). The ecological and economical value of urban soils estimated by the integral soil ecological index adjusted by the microbial correction coefficient was comparable to arable and fallow land, but was substantially less than in the natural areas, clearly indicating that investigate soils' functions (i.e., habitat for microorganisms and maintaining biodiversity) are not properly performed in urban areas. Taking into account additional soil functions, like carbon sequestration or run-off purification, would be necessary for a more comprehensive assessment of urban soils' quality and functions.

18.4 From Functional Assessment towards Best Management Practices to Maintain Urban Soils' Quality

18.4.1 Introduction

Urban soils are key components of urban ecosystems, therefore successful management of urban green infrastructure is impossible without considering soil quality. Most of the traditional practices in urban greenery and accomplishment lack attention to urban soil's function. Ignoring soil information in urban management practices likely results in soil and run-off contamination, emission of greenhouse gases and particle matters, degrading of urban vegetation. In this section we present different implementations of knowledge of urban soil quality and functions to manage urban ecosystems. Different technologies of urban soil's management are presented. Section 18.4.2 reviews rather straightforward practices to manage soils contaminated with heavy metals. Recommended practices are aggregated in a straightforward advice list for gardeners and landowners. Automated intellectual system described in Sect. 18.4.3 is a more complicated approach to distinguish the best management practices for urban soils depending on their functional use and disturbance level. Finally, Sect. 18.4.4 reviews different technologies of urban soil's constructions, representing the most radical approach of urban soil management by creating soil construction with the pre-given features to meet specific requirements (e.g., preserving ground water from contamination or maintaining green lawns in water scarcity conditions). The relevance of the proposed management practices is illustrated by the examples from New York, Moscow, and Dubai, where they were successfully implemented.

18.4.2 Framework Best Management Practices for Contaminated Urban Soils

Soil contamination is an important consideration when designating certain land for different uses. In general, industrial and commercial use of the lands are the least stringent in standards, while those for close human contact (such as food producing gardens and children playgrounds) should contain as little contaminants as possible. In many cases, instead of trying to remediate the soils that are often very expensive, careful soil survey and land-use planning (i.e., zoning designation) are the first step in reducing human health risk from urban soil contamination (Urban Soil Primer 2005). Different land uses require different managing strategies (Fig. 18.9). Human, animal, and ecological risk must be evaluated for any given site. Costs must be taken into consideration when developing short-term and long-term strategies.

For general use with minimal human interaction (e.g., forests, parks, recreation areas), maintaining a vegetated cover is important to limit the spread of contaminated soils by running water or wind. For ornamental gardens, cover crops can be very beneficial. They reduce nutrient leaching, increase fertility and organic matter content, suppress soil diseases and pests, attract beneficial insects and microbes, fix

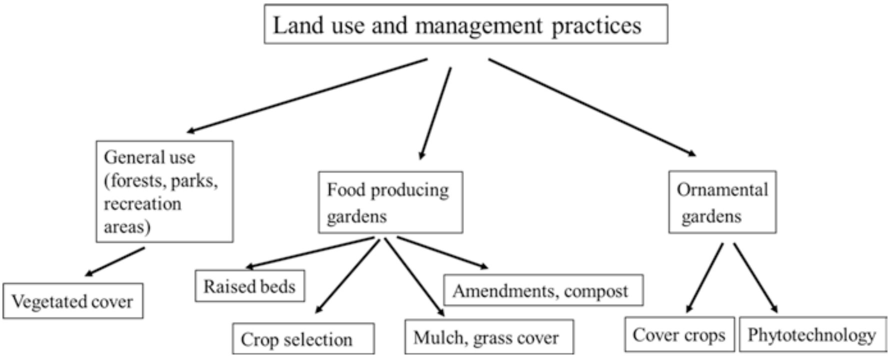


Fig. 18.9 Managing strategies required for different land uses

nitrogen, prevent soil erosion, and improve drainage and water retention in soils (Gugino et al. 2009).

Other strategies that can be applied in contaminated ornamental gardens are phytotechnologies. Phytotechnologies are a set of techniques that incorporate plants to remove, degrade, hold, or immobilize contamination in soil, groundwater, or surface water (Paz-Alberto et al. 2013). Climate, elevation, soil type and quality, properties of contaminates, and the capability of the plants and planting system used for each location influence the success and economic feasibility of a phytotechnology (EPA 542-F-10-009). For food producing gardens, contaminants can pose health risk through direct ingestion of soil or dust, or through the consumption of contaminant-bearing produce. Therefore, limiting both pathways are important. The Healthy Soils Healthy Communities Project, a partnership among Cornell University, New York State Department of Health and New York City Green Thumb, develop the ten Best Management Practices for urban gardeners: (1) use clean soil and compost; (2) use raised beds; (3) avoid treated wood; (4) maintain soil nutrients and pH; (5) cover (or mulch) soil; (6) keep an eye on children; (7) leave the soil in the garden; (8) wash your hands; (9) wash and/or peel produce; (10) put a barrier under play areas.

Most often, a physical barrier between contaminated ground soil and gardeners can be created by the addition of clean soil and organic matter placed within bed frames. Walkways can be covered with mulch or grass to protect children from exposure (EPA 542-F-10-009; Mitchell et al. 2014). The use of raised beds for urban produce gardens has been employed as an exposure reduction method for decades. They protect produce from weed invasion, avert soil compaction, provide good drainage, and serve as a barrier to pests (slugs and snails). Plant selection is an important consideration for gardening in contaminated soils. Usually, fruiting plants (tomatoes, squash, apple trees, pear trees, and berries) are acceptable for growing in potentially contaminated soil because of the low uptake rate of contaminants into fruits (McBride 2013). Another management strategy for soils with heavy metal contaminants is the addition of amendments. Amendments can dilute the contaminant levels in soils. An individual can immobilize lead in soil as long as the proper amendments are combined with the soil in necessary amounts. The following are possible amendments that are commonly used: Triple Super Phosphate, fishbone, Di Ammonium Phosphate, Mono Ammonium Phosphate, composts, and fertilizers. Such practices as maintenance of soil nutrients and pH, phytotechnologies, addition of amendments, and compost improve soil quality. Mulch cover, crop selection, and raised beds aid to prevent or reduce exposure to humans. Moreover, some basic rules like washing hands, leaving dirty shoes and equipment outside, washing and peeling produce would lessen a potential for inhalation or ingestion of contaminated soil particles.

18.4.3 AIS of Environmental Assessment, Monitoring, and Management of Urban Soils

The system of differentiated indicators and standards of urban soil quality, presented in Smagin et al. (2006) and Korchagina et al. (2014) (Sect. 18.3.1), was the basis for a pilot version of the automated intellectual system (AIS) of the municipal level for the environmental assessment, inventory, and selection of remediation technologies and reproduction (Smagin 2000). The initial data for AIS were taken from the soil survey results that were based on the aforementioned indicators of ecological status.

The input data contain quantitative information of a total land area, portions of open and sealed surfaces, and the GPS coordinates that are used for sampling certain functional elements. These data also include types of soils with their taxonomic names and portions of the total area, sanitary-hygienic, radioactive and toxicological indicators from a surface. Also included are the index bacteria of colon bacillus, the index of enterococcus, pathogenic bacteria, including salmonella, helminth's eggs, petroleum products content and 3.4-benzpyrene, background radiation, and littering. Moreover, horizon-based soil characteristics include (within 1 m) grain-size composition (texture), density of soil, pH, conductivity of a saturated solution, total organic carbon content, mineral nitrogen, mobile phosphorus, and potassium, as well as a total content of heavy metals and metalloids (1, 2 hazard classes: Pb, Cd, Hg, Zn, As). In addition to the analytical data, the survey results contain necessary land cadastral and address information of a site, survey dates, and contact information of the organization that has carried out the research. A survey sheet duplicates as an AIS interface for input of primary information, its subsequent processing and storage in the database of the urban soil sites register.

After characterization of each soil plot, an integrated assessment of the status of soil resources is performed taking into account the percentage of an individual soil type. If any soil issue is identified, AIS provides a portion of the land that the soil is located on and the GPS coordinates of sampling points. The following is also analyzed: the risk of radioactive contamination, general sanitary-epidemiological status, level of site pollution, threat to public health, dominant type of distribution of pollutants, compaction, salinization of electrolytes, and acidity/alkalinity of a contaminated area. A summary form generalizes characteristics of the resource according to its beneficial and harmful substances. A number of integrated indicators of the area are also calculated such as the potential for a site to have bioresources, a deficiency of biophilic elements, an integrated pollution index, an indicator of "ecological balance," or a degree of risk for marginal environments (Smagin et al. 2008).

To adapt *management decisions* for a certain site, an automated selection of technology from an address database is used. The database consists of methods of processing and reclaiming urban soils. Technological recommendations include remediation technologies, soil reproduction, and preventive approaches. Selection depends on a detected soil problem using encoding technology. In an automatic mode, an estimated cost is assessed on the basis of adaption of a certain technology with a price per unit area (weight of soil) and an area of a site with an identified problem. Considering the concept of ecological services, observations from AIS testing of Moscow city functional zones show that compensation of anthropogenic impact on urban soils and restoration costs should be around 20–300 €/ha. This cost is applicable for soils with shortages of elements, compaction, salinization, acidity/alkalinity issues, and pathogenic contamination. A cost of 500–1500 €/ha and above should be applied to soils with heavy metal and metalloid contamination, 3,4-benzpyrene spill, and those that must be exported to local landfills (Smagin et al. 2008).

18.4.4 Sustainable Soil Constructions for Urban Ecosystems

Constructing urban soils is a novel direction in engineering ecology, soil science, and urban management. It aims to develop a scientific background for design and construction of soil layers, phases, fluxes, and barriers to optimize features, regimes, and functions of urban soils (Smagin 2012). Materials used for soil construction are very variable including natural and modified organic and organomineral substances (peat and peat-based modifiers, composts, sewage sludge, humates, and zeolitic complexes), synthetic and polymer hydrogels, films, hydrophobic silicone resins, geotextile, plastic, and gabion items for soil-reclamation and geo-stabilization constructions. Literature review by Smagin and Sadovnikova (2015) provides the following categories of urban soil constructions:

- Artificial agricultural soils (ancient irrigated accumulative soil of river valleys, paddy soils, polders, Chinese piled-up soils "heylutu," "plaggen" soils in Northern Europe, horticultural soils, and dried-out peat lands;
- Soil constructions for sport games (football and rugby fields, tennis courts, golf courses, and race tracks); technical and geo-stabilization constructions (stone gabions, geo- and bio-textiles, bio-mats, geo-nets, and grades);
- Special isolating constructions (geo-membrane, protective screens, artificial geochemical barriers, etc.);
- Technical soil-reclamation constructions (drainage systems, terraces, dams and dikes, cascades, etc.);
- Constructions for water accumulation and salt-protection in arid landscapes and urban areas.

Urban constructions, implemented in urban greenery can give continuous surfaces (urban lawns) or discrete surfaces (constructions under trees and shrubs). Urban soil constructing is based on the artificial development of soil layers' series, simulating natural soil horizons and profiles. Each layer performs specific functions, including accumulation of bioresources or soil protection. The layers are created using organic soil modifiers, based on natural or synthetic biopolymers, together with the local grounds of different texture and dispersity (sands, loams, and clays). Root surface zone includes one or two layers, accumulating nutrients and moisture.

Both natural and synthetic materials (peat, hydrogels, and bio-polymers) mixed with local grounds are used for this purpose. Subsoil is likely separated from the topsoil by a "shield" from coarse-dispersion materials. This breaks off the capillaries, allowing for additional water "hanging" and storage, as well as for preventing from migration of salts and pollutants from the lower layers. Soil constructions' parameters (i.e., depth and sequences of soil layers and material for layer's construction) are estimated based on the fundamental laws of soil physics and models of energy and mass transfer, simulating soils as dynamic multiphase systems (Smagin 2003, 2012; Šimůnek et al. 1998, 2006). Technological projecting of urban soil's constructions implementing computer models of energy and mass transfer (i.e., HYDRUS model, Šimůnek et al. 1998, 2006) is presented in Fig. 18.10. Several scenarios of soil water distribution and water accumulation by the specific plant species are simulated for the initial conditions of the model soil constructions and after implementing specific soil modifiers. One or several accumulative layers at different depths are projected. Model results show that including accumulative layers based on the 0.2% synthetic hydrogels and "AridGrow" soil modifier enables substantial (from 5% to 20–80%) increasing of soil moisture in the root zone of the urban soil construction. This effect remains not only for the gravity water, but also when 3–4 mm/ day water uptake by urban lawns is considered. This increase in water holding and water accumulation capacity expands the period of non-deficit root water consumption (a period, when additional watering is not necessary) on 10–15 days (for the sandy substrates) to 30 days (one accumulative layer at the 10 cm depth) or 40 days (two accumulative layers at the 10 cm depth) (Fig. 18.10d, vertical dotted arrows). Water consumption of 2 mm/day represents critical conditions of lawns' wilting. HYDRUS-1D model results were validated by laboratory experiments on the small simulators of urban soil constructions, and high modeling accuracy was showed (Fig. 18.10a) (Smagin 2012). The developed water-accumulated and salt-protected soil constructions were tested afterwards for irrigation agriculture in arid climates in Persian Gulf countries and for urban environment of Moscow megapolis. Both experiments confirmed high effectiveness of the developed soil constructions (Smagin 2006, 2012; Smagin et al. 2005; Smagin and Sadovnikova 2015).

Another example can be given by soil constructions under green lawns at the municipal greenery experimental station in Dubai. The tested soil constructions included peat-based soil modifier and swelling polymer hydrogel. This novel technology resulted in 2–2.5 time increase of green-lawn biomass (*Paspalum hybrid*)

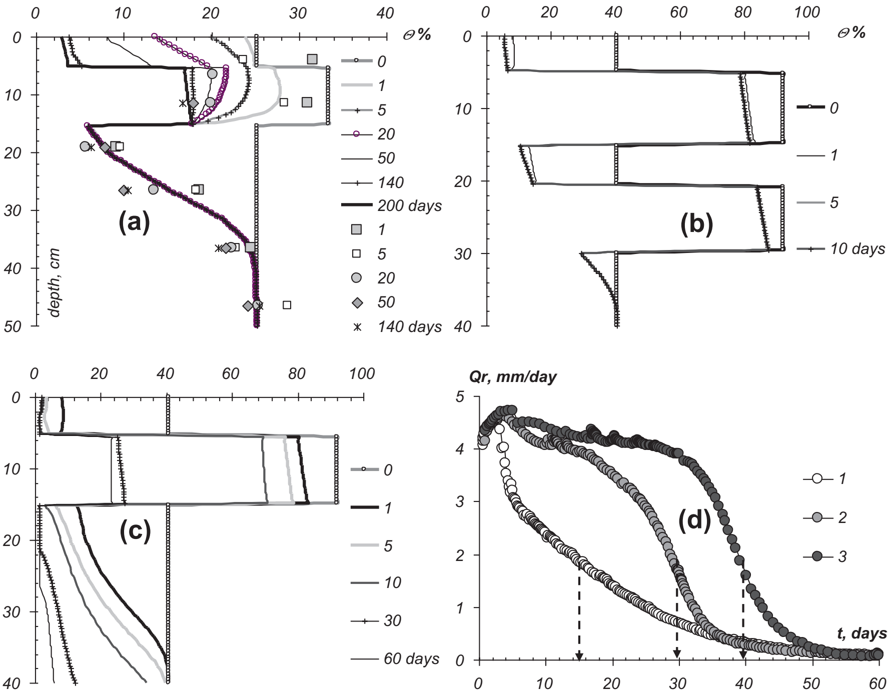


Fig. 18.10 Technological modeling of the layered water_accumulative soil constructions with the crushed_stone screen with the use of HYDRUS-1D software: Θ—volumetric water content (the regime of free gravitational water outflow after saturation): (**a**) construction with a 10 cm thick accumulative layer of 0.2% synthetic swellable hydrogel (experimental data are given by symbols), (**b**) construction with two layers of the peat–sapropel soil modifier, (**c**) the same for the regime of water uptake by the roots of lawn grasses, (**d**) dynamics of water expenditure for transpiration (*Qr*, mm/day) with arrows indicating critical water consumption upon irreversible wilting of the grasses for (1) sand, (2) one layer of the peat–sapropel modifier, and (3) two layers of the peat–sapropel modifier

and improvement of the lawn quality estimated the chlorophyll content (Fig. 18.11a, c). The implemented technology allowed minimizing soil water losses on 30–50% and prevented secondary salinization. Monitoring salt regime based on Ec measuring in soil pastes showed clear tendency to desalinization of the top 30 cm of the soil constructions in first 3 month of the experiment (Fig. 18.11e).

The developed soil constructions have a huge potential for implementation in urban greenery as an alternative of the conventional technologies based on permanent adding of organic substrates to soil surface, since the low effectiveness and high costs of the latter ones were proven by some research (Smagin 2006, 2012; Vasenev et al. 2014a, 2015). Green lawns, glower beds along the roads, in house courts, and in public places provide the niche and the market for implementing technologies of soil construction. Developed constructions shall be sustainable

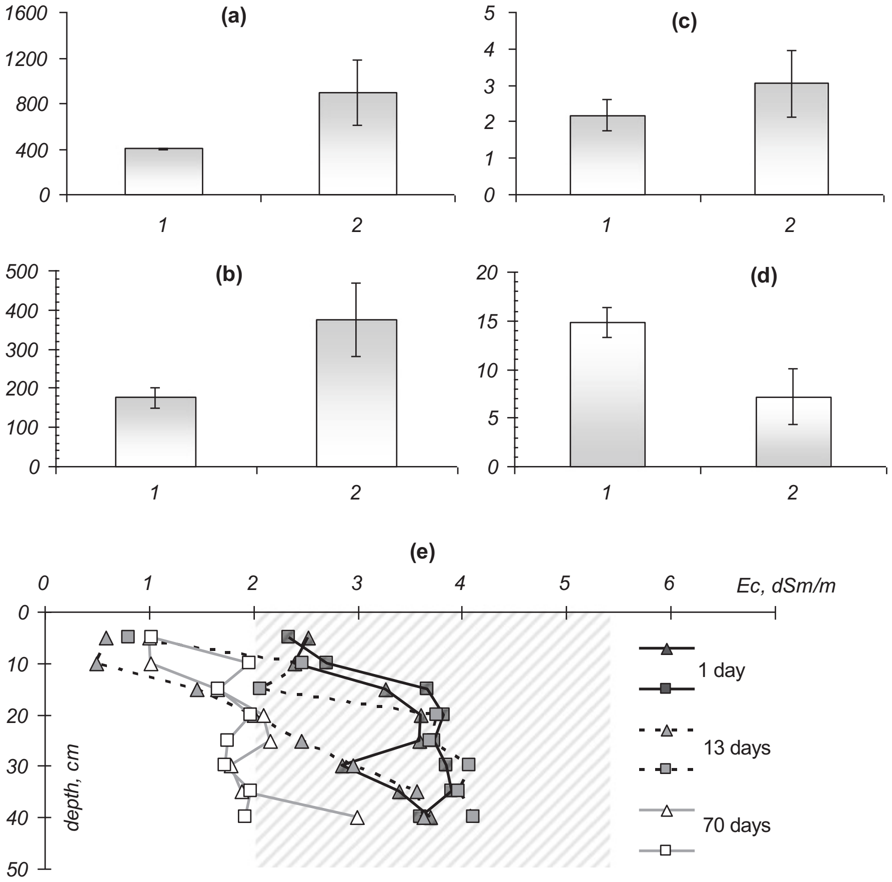


Fig. 18.11 Experimental results of growing green lawns at the station of landscape and gardening of Dubai: fresh phytomass (g/m^2) (**a**); absolutely dry phytomass (g/m^2) (**b**); chlorophyll content (mg/g) (**c**); irrigation water (l/m^2 day) (**d**); electric conductivity (Ec) of soil pores solutions (**e**). Experimental sites include control (1) and developed soil construction (2). Triangles show SPH treatments, squares show low-moor peat treatment, and hatching signifies salinization zones

to bioclimatic conditions and anthropogenic pressures (i.e., salinization and contamination). They shall provide key functions for urban vegetation, including nutrient, water, and heat accumulation. Specific features and high heterogeneity of urban soils will require for additional experiments to adapt technologies of soils' constructions to urban environments. However, successful experience obtained in different climates and managements types assures the possibility of such adaptation and affirms substantial increase of soil quality and in result. For example, implementing these constructions in specific arid conditions allowed to saving half of watering expenditures, which was a limiting factor for agricultural development at the deserted areas.

18.4.5 Conclusion

Although urbanization is increasingly important, its environmental consequences for soils' functions and quality are still poorly known. Urban soil is a very complicated object to study, access, and manage. Urban soils provide multiple functions and are exposed to numerous threats. Anthropogenic factor dominates formation and functioning of urban soils, contributing to their heterogeneity. High spatial variability and temporal dynamics of urban soils' features and functions require for advanced approaches to monitor, access, and manage their quality.

In the current chapter we reviewed the key soil functions proposed by European, American, and Russian classifications and analyzed their performance for the specific case of urban soils. Different methods and indicators to monitor and assess urban soils' quality were discussed, including chemical and microbiological indexes, soil regimes and supply of nutrients, water, and contaminants. We proved that conventional methods based on agricultural or sanitary parameters underestimate urban soil's quality. Only an integral complex assessment, incorporating static and dynamic parameters, physical, chemical, and biological features, bioclimatic and economic indexes, can give an adequate value to the role, which urban soils play for environment and society. Different methods and implementations of the integral assessment of urban soils' quality were described for the case studies for the megapolises with different climatic, economic, and historical conditions, e.g., Moscow, New York, and Dubai.

Relevant assessments of urban soils' functions and quality provide the basic information for a proper management of urban soils and urban ecosystems. We demonstrated that urban soil's management, including recommendations for gardeners, best management practices, automated intellectual systems, and urban soils' constructions, are much more efficient when the multiple functions, which they perform, are considered.

Urban soils are the most dependent on the anthropogenic factor. They are altered or artificially created by humans and for humans. Smart management of urban soil's quality can substantially increase functions and services of urban soils, whereas extensive and thoughtless use can result to their degrading. Management practices, currently implemented for urban sols in the major large cities, are still rather far from being sustainable, therefore maintaining urban soils' quality remains an important issue. The problems highlighted and the solutions proposed in the chapter contribute to development of the smart management practices for urban soils' functions and quality, which is an integral component of the sustainable cities of the future.

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