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Guideline Values for the Content of Chemical Elements in Soils of Urban Functional Zones: A Review

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Abstract—The Russian soil quality assessment system, where the guideline values for the content of heavy metals and metalloids derived for arable lands (mostly, in terms of the general sanitary indicator of harmfulness) are applied to soils of the residential area and the protected area of water supply sources, can be updated using international experience, e.g., substantiation of generic values for urban functional zones since, with a few exceptions, the Russian soil quality guidelines are the same for all soils of the country. In order to assess the applicability of foreign approaches to Russian realities, we have thoroughly analyzed the original and most developed legislation systems of the soil quality control in cities of Germany, Canada, and the United States, as well as the systems of Australia, New Zealand, Republic of South Africa, and the countries of the European Union, where the values are land use specific. In this paper, we summarize the principles of soil quality assessment for the contents of chemical elements, brief the methodology used in different countries and the consequences of exceeding the standards, and highlight some clues for improving the Russian soil quality assessment system. The Russian soil quality assessment system can be improved and updated by substantiating (i) the land use specific standards for cities with the focus on actual subjects of standardization (the health of ecosystems, children, or adults); (ii) the standards for different geochemical environments taking into account the specific features of migration of substances; and (iii) the standards for the soil materials used to construct lawns and roadside areas. In addition, we suggest (i) developing a comprehensive system of management decisions for the case when soil quality standards are exceeded; (ii) legitimizing the concept of historical pollution that existed before the commencement of business activities; and (iii) establishing the minimum volume of soil and the depth or set of soil horizons to be remediated or removed due to pollution.

Keywords: soil pollution, quality standards, environmental policy, human health risk assessment, One Health approach, potentially toxic elements

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INTRODUCTION

Diverse environmental pollution by a wide range of substances stimulates the development of systems for soil quality assessment in many countries [2, 4, 6, 8, 13]. The proposed guideline standards may be the same for the whole country or different depending on soil properties or land use (Table 1).

The cities differ from rural or other areas by an increased population density, dust content, the presence of specially constructed soils, and other specific features in the humans–environment interaction. Since most of the planet's inhabitants live in cities, the specific urban features associated with city zoning should be taken into account when developing the standards for urban soil with regard to the content of chemical elements (**CEs**). This specificity refers to the allocation of areas to different functions, for example, residential purposes, transport, entertainment and leisure (parks, playgrounds, and other recreation facilities), production, warehousing, and trade. In addition, different urban trends and specific features should be considered, such as low- and high-rise construction, central or individual heating (or absence of either), the presence of individual plots for growing agricultural products, and the share of paved areas. All these factors determine the tightness of the interaction between humans and soil in an individual city or country, which can be direct (skin contacts and inhalation or ingestion of dust) and indirect (via eating food and drinking water that have contacted the urban soil). In addition, the chemicals contained in the city dust of a non-soil origin as well as the food and drinking water derived from other countries influence on human health, too.

Development of the hygienic standards for soil quality assessment in Russia (including soils of cities, settlements and towns) with respect to the content of abiotic chemical substances follows the laws for sanitary and hygienic welfare of population (Decree of the Government of the Russian Federation of February 13,

Table 1. Differentiation of soil quality standards for the content of chemical elements in selected countries

Country	Soil properties	Land use	Grown crops	Reference
Australia	No	Yes	Yes	[15, 23, 31, 40]
Austria	No	Yes	No	[18]
Belgium	No	Yes	No	[18]
Brazil	No	Yes	No	[38]
Canada	Yes[2]	Yes	No	[19]
China	No	Yes	Yes	[20, 39]
Czech Republic	Yes	No	No	[18]
Denmark	No	No	No	[18]
Finland	No	No	No	[18]
France	Yes[3]	No	No	[18]
Germany	Yes[1]	Yes	Yes[2]	[18]
Italy	No	Yes	No	[18]
Japan	No	Yes	No	[26, 44]
Lithuania	Yes	Yes[2]	No	[18]
The Netherlands	No	No	No	[18]
New Zealand	No	Yes	Yes	[15]
Poland	Yes	Yes	No	[18, 47]
RSA	Yes	Yes	No	[22, 28]
Russia	Yes[1]	No	No	SanPiN 1.2.3685-21
Slovakia	Yes	Yes[1]	No	[18]
Spain[5]	No	Yes	No[4]	[18]
Sweden	No	Yes	No	[18]
United States	No	Yes	No	[25]

[1] Part of the guideline values (Germany, precaution levels; and Slovakia, limit values for agricultural lands); [2] for individual substances (Germany, more strict standards for Cd when growing wheat for bread and Cu for sheep pastures; Canada, PAHs and hydrocarbons; Lithuania, hydrocarbons; and Japan, As, Cd, and Cu in paddy fields); [3] usage sensible/insensible; [4] additional standards of safe levels for soil and aquatic organisms and terrestrial vertebrates; and [5] only organic substances are standardized.

2019 no 149 "On the Development, Introduction, and Revision of the Environmental Quality Standards for the Chemical and Physical Environmental Parameters and Approval of the Guidelines for Environmental Protection that Regulate the Technological Characteristics of the Best Available Technologies"). However, the ecological soil quality standards are not officially approved. The Russian system for assessing the content of pollutants in soil relies on the approaches that have not been long revised with respect to the risk of adverse effects and improved instrumental analytical techniques [7] although some original approaches have been proposed. In particular, the method based on a vertical distribution of pollutants and soil density was proposed to assess the pollution of urban soils with heavy metals. In this approach, the amount of pollutant in a provisionally standard soil layer is used as an integral indicator of pollution [1, 5, 10]; so far, this is applied only for standardization of soil quality according to radionuclides.

In Russia, the threshold limit value is the maximum concentration of a substance that has no adverse effects on human health and soil (including its main ecological functions as well as enzyme and microbiological activities) calculated for the arable horizon. In addition to farmlands, these standards are also recommended for the soils within residential areas (Sanitary Regulation and Standard SanPiN 1.2.3685-21). Development of such standards is a long-term scientifically substantiated process initially implying assessment of stability and change in mobility of a substance to be regulated in soils differing in organic matter content, acidity, and moisture (Methodical Recommendations, 1982; Hygienic Standard GN 2.1.7.2041-06); however, this approach has been implemented only for manganese content.

In Moscow, the Law of the City of Moscow no. 31 of June 4, 2007 "On the Urban soils" declares that it is necessary to set up the standards and levels of soil quality threshold limits depending on the main soil

Table 2. Characteristics used in the countries with the most advanced approaches to soil quality standardization

Country	Protected object		Hazard characteristics			Risk assessment		Scientific basis							
								local background		universality				updates	diet
	ecosystem	humans	translocation	water migration	aerial migration	negative impact	cancer development	reference value	basis for standard	land use	soil-specific	mixed effects	site-specific risk assessment		
Canada	+	+	+	+	+	+	+	+	–	+	–	–	+	+	+
Germany	–	+	+	+	–	+	+	–	–	+	–	–	+	–	+
The Netherlands	+	+	+	+	+	+	+	+	–	–	–	–	+	–	+
Russia	+	+	+	+	+	–	–	+	–	–	+	+	–	–	+
United States	+	+	+	+	+	+	+	+	–	+	–	+	+	–	+

characteristics and land use. However, these guideline values have not been developed so far. At the Federal level, the standards used in Russia are maximally strict (with few exceptions) for all soils, which are safe for a normal functioning of biota and humans [8, 42]. However, this approach is not justified in almost completely paved historical centers of cities with Ekranic Technosols, where no crops are grown, human exposure is short, and the presence of biota is unlikely because of the absence of necessary ecological niches (lawns and water bodies) as well as of anthropogenic soils and, the more so, of natural soils.

Development of the domestic system for soil quality assessment with respect to the content of CEs requires a comprehensive analysis of the relevant specific features of the guidelines for environmental management in the leading countries of the world.

The United States, Canada, Russia, and the Netherlands are the world leaders in the number of CEs subject to the corresponding standards of their content in the soil [8]. Five main approaches to the soil quality assessment with respect to the content of potentially toxic substances are traditionally distinguished: Russian, Dutch, German, Canadian, and American [18, 31, 42]. A specific feature in the elaboration of soil quality standards is the use of a large number of input characteristics (Table 2), including the subject and object of standardization and the assessment of the risk of negative effects, regional soil and geochemical background, and the consequences for the ecosystem and landowner if a standard is exceeded [8, 41].

The Russian, Dutch, and Canadian approaches combine the focus on the human and ecosystem health [17, 21, 43], being close to the One Health approach, actively developed [32, 35, 36]. In the United States, legislation contains certain standards for ecosystems in general and for their individual components as well as the standards related to the population health [25]. The German standards are focused on minimizing the risk for humans to take in dangerous amounts of potential toxic elements with water and food [16]. The five main approaches to soil quality standardization are successfully adopted by other countries taking into account the local specific features. The successful examples of applying international experience in development or updates of the national systems for the ecological soil quality assessment are numerous [4, 6, 9, 11, 15, 18, 45, 48].

Several countries, including Russia, use differential approach when elaborating their national standards by distinguishing the soils with contrasting characteristics related to texture, total organic carbon content (mainly for organic pollutants), and, rarer, pH. However, the soil quality standards are differentiated depending on the functional zoning of the territory and the use of areas without taking into account soil quality. Frequently, urban residential, recreation, and industrial zones are distinguished in the soil quality assessment according to the content of substances (Table 3).

The goal of this review is to summarize the international experience in the urban soil quality assessment according to CE content. We omitted a detailed characterization of agricultural land standards since it has been comprehensively described earlier [8, 42] to concentrate on the urban territories. Our focus is the analysis of the currently applied and legislatively approved approaches to soil quality assessment with respect to inorganic pollutants, since the relevant literature describes numerous proposals for estimating the degree of environmental pollution that have not been yet used in practice [3, 12, 14, 24].

Table 3. Differentiation of soil quality standards according to the total content of CE in different countries depending on functional zoning of cities

<table>
<tr><th rowspan="2">Country</th><th colspan="6">Functional zone</th><th rowspan="2">Reference</th></tr>
<tr><th>residential</th><th>green</th><th>recreation</th><th>commercial</th><th>industrial</th><th>transportation</th></tr>
<tr><td>Australia</td><td>++</td><td>–</td><td>+</td><td colspan="2">+</td><td>–</td><td>[15, 23, 31, 40]</td></tr>
<tr><td>Austria</td><td colspan="3">+</td><td>–</td><td>–</td><td>–</td><td>[18]</td></tr>
<tr><td>Belgium (for all country and jointly for Flanders and Brussels-Capital Region)</td><td>+ +</td><td>+</td><td>+</td><td>–</td><td>++</td><td>–</td><td>[18]</td></tr>
<tr><td>Belgium (Wallonia)</td><td>+</td><td>–</td><td>+</td><td>–</td><td colspan="2">+</td><td>[18]</td></tr>
<tr><td>Germany</td><td>+</td><td colspan="2">++</td><td>–</td><td>+</td><td>–</td><td>[18]</td></tr>
<tr><td>Spain*</td><td>+</td><td>–</td><td>–</td><td>–</td><td>+</td><td>–</td><td>[18]</td></tr>
<tr><td>Italy</td><td colspan="2">+</td><td>–</td><td colspan="2">+</td><td>–</td><td>[18]</td></tr>
<tr><td>Canada</td><td colspan="2">+</td><td>–</td><td>+</td><td>+</td><td>–</td><td>[19]</td></tr>
<tr><td>New Zealand</td><td>+</td><td colspan="2">+</td><td>+</td><td>–</td><td>–</td><td>[15]</td></tr>
<tr><td>Poland</td><td colspan="4">+</td><td colspan="2">+</td><td>[18, 47]</td></tr>
<tr><td>United States</td><td>+</td><td>–</td><td>–</td><td>–</td><td>+</td><td>–</td><td>[25]</td></tr>
<tr><td>Republic of South Africa</td><td>++</td><td>–</td><td>–</td><td colspan="2">+</td><td>–</td><td>[22, 28]</td></tr>
</table>

* Only organic contaminants are standardized. The number of plus signs corresponds to the number of developed standards.

SOIL QUALITY ASSESSMENT SYSTEMS

Canada. The Soil Quality Guidelines (**SQG**[1]) on the total CE content were first introduced in 1991 and are periodically updated (the last revision for inorganic pollutant was in 2018). The SQGs are land use specific (Table S1) and are aimed at the preservation of population health, living organisms, and soil microbiological processes (nitrification, nitrogen fixation, soil respiration, and organic matter decomposition) from negative consequences.

The SQGs distinguish three functional zones in cities. Residential–park areas comprise residential zone and the recreation zones without nature conservation territories. Commercial lands are used for shopping facilities, warehouses, hotels, food spots, and so on. Industrial zone houses production objects with limited access.

The SQGs were developed based on the data on CE toxicity for soil fauna, their migration in soil, and food chains, humans included. Both federal and regional (for individual provinces and territories) standards are used in Canada [9].

United States uses a multilevel system for standardization of CEs in soil for about 30 years; this system comprises both the general recommendations and the standards of a Federal level, developed by the US Environmental Protection Agency (**EPA**), and the state-level laws for decision making at a local level. Regional screening levels (**RSLs**) and regional removal management levels (**RMLs**) are applicable to the residential and industrial zones (Table S2).

[1] For some organic pollutants, the SQGs for each functional zones were calculated separately for the coarse (sand) and fine (silt/clay) soils.

RSLs are used to identify pollutants and the areas subject to the regulation by Federal authorities, while RMLs are used to define the territories where polluted soils can be removed [5, 25]. Both guidelines are based on the risk assessment using the target hazard quotient (**THQ**) and hazard quotient (**HQ**). The American screening values for soils mainly correspond to a risk level of 10^{-6} for carcinogenic substances and HQ = 1 for noncarcinogenic ones. THQ is used for calculating the concentration below which the negative consequences for the sensitive population group in the case of a multielemental pollution is unlikely. In this situation, the assumed risk amounts to 10^{-6} to 10^{-4} for carcinogenic substances, while the noncarcinogenic risk must be added only for the substances with a similar toxic endpoint and mechanism of action.

EU countries[2]**.** *Germany.* The Federal standards for the content of heavy metals and metalloids (**HMMs**) in soil were approved in this country in 1999. They include trigger, action, and precaution levels for four functional zones, namely, agricultural (including individual agricultural and garden standards), residential, recreational and park (including separate standards for children's playgrounds), and industrial zones. These standards rely on three estimates on the corresponding impacts: the migration routes of substances in the soil–man and soil–plant systems (separately in the context of the quality of their production or a slowdown of plant growth) and acceptable additional load on the soils of different textures.

Only trigger values (Table S3) have been developed for residential and industrial zones (when these values are exceeded, monitoring is launched with

[2] This section is based on [18] unless stated otherwise.

subsequent assessment of pollution hazard). The authorized institution determines whether the polluted plot matches the criteria for remediation taking into account the soil type, mobility of the toxicant, and other conditions [18].

The final trigger value (T) for children's playgrounds, residential area, and parks is the minimal value based on the ingesting or inhaling a substance calculated using Eqs. (1)–(4), where Eq. (1) describes the ingesting of noncarcinogenic substances; Eq. (2), ingesting of carcinogenic substances; Eq. (3), inhaling of noncarcinogenic substances; and Eq. (4) inhaling of carcinogenic substances (Table S4):

$$\mathrm{T} = \frac{Dtb \times (f - 0.8)}{\Pi}, \quad (1)$$

$$\mathrm{T} = \frac{Dtb \times f \times 8.75}{\Pi}, \quad (2)$$

$$\mathrm{T} = \frac{Dtb \times f}{\Pi \times fa}, \quad (3)$$

and

$$\mathrm{T} = \frac{Dtb \times f \times 8.75}{\Pi \times fa}, \quad (4)$$

where *f* is the factor risk for adverse consequences for sensitive human population (5 for carcinogenic substances and 1.4 to 10.0 for noncarcinogenic ones); Π, daily input of the substance to human organism; *fa,* accumulation factor (5 for inorganic and 10 for organic substances); and *Dtb,* the value equivalent to the level at which no negative effects in the sensitive human population are observed, determined according to toxicological data as a tolerable body dose. Usually, *Dtb* is computed based on the minimal level at which negative effects are observed in animals using correction coefficients of 1 to 10 depending on the degree of uncertainly. Thus, the trigger values for the same CE in residential, park–recreation, and industrial zones differ 2-, 5-, and 5.5–13-fold, respectively, from the analogous levels in the children's playground.

Eq. (5) for the T value in industrial zone takes into account the dust concentration in the air (0.325 mg/m^3) and the risk for adverse consequences with the help of coefficient *Z* for carcinogenic ($Z = 25.6$) and noncarcinogenic ($Z = 14.6$) substances; it is calculated based on the time spent in the zone using a correction factor (Table S4):

$$\mathrm{T} = \frac{Dtb \times f \times Z}{0.325 \times fa}. \quad (5)$$

Austria uses the principles of integrated environmental protection, which were introduced to the Constitution in 1984 as the basis for protection of human environment aiming to preserve clean air, surface waters, and soils and to prevent noise pollution. The Soil Screening Values (**SSVs**) used for risk assessment in contaminated areas were proposed by the expert team based on the analysis of 15 national and regional characteristics in the EU countries rather than computed using particular models. Two groups of standards were developed in this country, namely, human health screening values and ecological screening values. The first group of the standards (Table S5) is based on the assumption on the ingestion of pollutants by children and the second group of the standards is applied to farmlands. These values reflect the possibility of an increased passage of pollutant to plants with additional estimation of the probability of bioavailability via assaying the level of the mobile HMM fractions extracted from soil with NH_4NO_3 and distinguishing between two grades of potential risk: (1) production of low quality food and forage and (2) a decrease in a plant growth rate [18].

Belgium uses the standards applied to its whole territory and individually[3] in three autonomous regions: Flemish, Walloon, and Brussels-Capital Regions. The federal-level standards have been developed for (1) special territories (green areas with a high biological value, parks, forest areas of cemeteries, lands under forests, afforested sites, farmlands, and sanitary protection zones of drinking water supplies; (2) residential zone (proper residential, mixed, and sport–recreation zones, including the open industrial and public objects); and (3) city industrial zones (of transportation activities, including port, vehicle and railroad sectors). There are also other SSVs (Table S6), namely, background values and soil clean-up standards (**SCSs**). The former values for HMMs correspond to 90th percentile of the HMM content in the topsoil layer of the Flemish Region (without Brussels) and for most organic pollutants, lower detection limit. The SCSs have been defined using the assessment of negative consequences for children's and adult people health without correcting the bioavailability of pollutant entering the body via different routes in urban functional zones (residential, recreation, and industrial) as well as on the farm and natural lands using the Dutch, American, and Canadian approaches and the EU and WHO recommendations.

Background values are the level characteristic of unpolluted soils and are used for remediation. The values exceeding SCS indicate the possibility of harmful consequences for human health and environment and the need of remediation in the case of a new pollution that appeared after the decree of 1995, which introduced these standards.

Two groups of standards were developed in Wallonia (Table S7) to characterize the background soils of this region: reference values (**RVs**) and different risk values for the negative effects, namely, trigger values (**TVs**) and intervention values (**IVs**). Soil is regarded as

[3] The HMM standards used in the Flemish and Brussels-Capital Regions (the latter resides within the former) are the same as the federal standards.

unpolluted if the content of pollutant is below RV and likely unpolluted in the RV–TV range. In both cases, the risk of pollution is regarded as acceptable, requiring no actions. If the corresponding values exceed the TV level, the soil is regarded as polluted unless it is proved that this excess is associated with some specific features of the geochemical background. Any ecological actions are undertaken only in the case of a new pollution or need the corresponding measured for a historical pollution that appeared before 1995. The ecological measures are obligatory only when the content of pollutant exceeds the IV level.

The focus objects of the Wallonian system for the soil quality assessment are humans (children for natural, residential, recreation, and commercial zones and adults for industrial areas), waters, soil microbiota, and herbivores (for farmlands). The standards are developed using Dutch, American and Canadian approaches.

Spain. The Spanish Generic Values of Reference (**GVR**[4]) for organic pollutants were elaborated using the risk assessment in three variants (industrial, residential, and natural) according to the worst scenario and issued in the Royal Decree of 2005. Human health protection is present in all three variants and that of ecosystems, only in the natural variant of land use. For each variant of land use, the hazard to human health is assessed according to the most realistic scenario, and the route of impacts for the most sensitive recipients. The ecological risk is assessed applying chemical analysis, direct tests for toxicity, and three major recipients: soil, water, and terrestrial organisms.

These Generic Values of Reference correspond to trigger values: they indicate the need in the site-specific risk assessment for negative consequences. Soil is regarded as polluted when direct toxicological tests of soil samples or extracts show a very high level of acute toxicity.

Italy. The Ministerial Decree on soil pollution was issued in 1999. It refers to two functional zones: (1) residential or public (green) zone and (2) industrial or commercial zone (similar guidelines existed earlier in individual Italian regions). If the specified values are exceeded[5] (Table S8), the territory is regarded as polluted and the landowner must adjust the concentration of the corresponding pollutant to the level of natural background.

The Italian soil quality standards are focused exclusively on human health without focusing on ecological risks. They were developed according to the worst scenario concept, which is now gradually rejected for more realistic variant [34].

Poland use the guidelines officially approved in 2001 as the corresponding law in the regulations on polluted lands. In the case of pollution, the landowner must reduce the content of the corresponding substance to the level below the values specified in the Soil Quality Standards. These standards are differentiated for three groups of lands according to their planned and current use. The group B and C standards refer to different depths and are additionally divided depending on the saturated hydraulic conductivity of soil (Table S9). However, the scientific grounds for these standards are vague.

Group A comprises the lands of nature reserves specified in the corresponding laws; group B, agricultural lands (except for ponds and ditches), forests, planted forest and shrub stands, wastelands, and cultivated lands as well as urbanized areas except for industrial, mining, and transport areas, which form group C.

Australia and New Zealand. The Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites [15] were officially approved in 1992. They form the background of soil quality evaluation for the content of potentially toxic substances. The Australian Guidelines substantiate the assessment levels for human health, Health Investigation Levels (**HILs;** Table S10), derived from the properties of the background soil and geochemical surveys of four capitals except for Perth, and phytotoxicological experiments [23, 31].

The standard residential zone is represented by territories with a house and a yard where no poultry is kept, while fruits and vegetables are grown in an amount of ≤10% of the daily diet of residents. This zone includes the centers for daily childcare, kindergartens, and schools, too. Some standards for residential zone refer to the territories with minimal contact between soil and people because of high-rise buildings and paved streets. The HILs of group E are applicable to recreation areas and secondary schools. Commercial and industrial lands comprise trade and industrial enterprises and so on.

In addition to HILs, Environmental Investigation Levels (**EILs**), temporary ecological standards, are used in Australia. Using foreign standards is permitted for the substances the content of which is not regulated in this country [23]. And some regional standards exist as well [40]. Analogous practice is characteristic of Chile [27] and India [29], which have no well-elaborated system for soil quality standardization according to the content of potentially toxic elements.

Although the approaches used in Australia and New Zealand are similar, and the foundations for the standards and functional zoning systems are common [8], the threshold levels and the list of standardized CEs differ considerably [37]. Three functional zones are distinguished in the cities of New Zealand (Table S11). For these zones, the soil contaminant values safe for human health are established. In addition, it is specified that the standards for several CEs safe for humans can be hazardous for plants and need individual assessment.

[4] The standards are developed only for organic pollutants.
[5] A 10% deviation is permitted.

The **Republic of South Africa (RSA)** utilizes the Soil Screening Values. As the first step in the case SSVs are exceeded, a multistage justification is launched to determine the need in site-specific assessment of the risk for negative impacts prior to the decision making on remediation of the territory and implementation of the relevant management solutions. The SSV1 standards are applicable to the entire territory of the country.[6] As for the SSV2, their use is confined to particular functional zones that contain no water bodies used as sources of drinking water within a radius of 1 km (Table S12). The SSV2 standard relies on the risk for children's health in informal and standard settlements and adults health in commercial and industrial zones [22, 28].

CONCLUSIONS

Children's health (prevalently for the residential and recreation zones), health of adults (for the remaining functional zones), and health of ecosystems (for forest–park, recreation, and residential territories) are the focus objects for the soil quality assessment. The standards are most frequently developed for residential, recreation, and industrial zones as the territories most contrasting in the human exposure duration, the variants of their interaction with the soil, and the objects whose health must be primarily protected.

The Russian system for evaluation of concentrations of potentially toxic elements in soils is focused on the health of humans and ecosystems as well as on agricultural production of the proper quality. In the context of urban ecosystems, the last two objects are not relevant because of the absence of agrocenoses and a large share of paved space (Ekranic Technosols). Based on the international experience, the Russian system for the soil quality assessment with regard to the content of potentially toxic elements can be improved by

– Substantiating the threshold values for urban functional zones (park, residential, transport, industrial, and so on);

– Focusing only on the most relevant objects in different urban functional zones, such as the health of ecosystems (park and recreation zone), children (recreation zone and territories of kindergartens, playgrounds, and schools), or adults (residential, transport, and industrial zones);

– Substantiating the system of standards with different degrees of strictness with the minimal values for forest stands, parks, and playgrounds; intermediate values for residential zone; and the highest in commercial, transport, and industrial zones;

[6] The SSVs are developed for anions: chlorides (12 g/kg), fluorides (0.03 g/kg), sulfates (4 g/kg), and total nitrates and nitrites (0.12 g/kg). They refer to the whole territory of the country and are independent of the land use type.

– Elaborating a consistent system of decision making and implemented activities for the cases when the corresponding soil quality standards are exceeded ranging from site-specific monitoring to fines and obligatory remediation of the damaged lands;

– Legislatively defining the concept of historical (old) contamination, which existed before the commencement of certain activities;

– Introducing the standards for different geochemical situations (separately for acidic and alkaline soils with an oxidative environment as well as acidic and alkaline soils with gley and hydrogen-sulfidic environment) taking into account the specific features in CE migration and accumulation on geochemical barriers and for the material used for the surface layers of flowerbeds, lawns, and roadsides; and

– Defining the minimal soil volume to be remediated as well as the depths or soil horizons covered by the corresponding standard.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

SUPPLEMENTARY INFORMATION

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Table S1. Canadian SQG for HMM total content in urban soils of different land use [19], mg/kg.

Table S2. Levels used for assessing urban soil quality in the United States (total content) [25].

Table S3. Trigger levels used for standardization of total HMM content in German soils [16], mg/kg.

Table S4. Input parameters for calculation of trigger levels in Germany [18].

Table S5. Guideline values for the total CE content in the topsoil (0–10-cm) in the areas (residential areas and sports grounds) where a direct hazard from oral intake by children cannot be excluded [18], mg/kg.

Table S6. Environmental standards used for the urban soil quality assessment in Belgium (whole country), Flanders, and Brussels [18], mg/kg.

Table S7. Values used in the Walloon Region (Belgium) for the urban soil quality assessment [18], mg/kg (total content).

Table S8. Guideline values used in Italy for the soil quality assessment according to the total content of CEs [18], mg/kg.

Table S9. Guidelines used in Poland for the total content of HMMs in the urban soils and sediments [18], mg/kg.

Table S10. HILs used for assessment of soil quality in functional zones of Australian residential locations according to the total content of CEs [23], mg/kg.

Table S11. Levels used for assessment of soil quality in the cities of New Zealand according to the total content of HMM [37], mg/kg.

Table S12. Values used for assessment of urban soil quality in the Republic of South Africa according to bulk HMM content [22, 28], mg/kg.

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