Influence of Latitudinal Zonality on Some Chemical Properties of Urban Soils

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Abstract. In this study, the database of properties of urban soils was created to assess the influence of zonal features of natural factors of soils, situated in urban areas. The database contains more than 135 cities located in different natural zones all over the world from the Arctic tundra to equatorial tropics. A comparison based on two features: soil organic carbon (SOC) and water-extracted pH. A number of statistical indicators such as average value, minimum and maximum values, standard deviation, variation, correlation coefficients were calculated for each zone and feature.

The analysis of the results showed that the variation in carbon content values in urban soils is significantly higher in comparison with background soils. This fact can be explained by the influence of anthropogenic factor on the processes of organic matter reduction and accumulation in the soil. At the same time the average carbon content in urban soils in most cases is much higher than in natural soil and in general, there is a trend: the difference between SOC in urban and natural soils increases to the north and gradually decreases to the south. However, a comparative analysis of soil-bioclimatic zones neither in climatic nor in facial series there is no trend can be observed. This means that the characteristics of the SOC of urban soils are not zonal and the observed trend can be explained by the intensity of human impact. The comparison of the average values of pH in the urban and natural has not shown any statistically significant difference. However the comparison of maximum values of water-extracted pH for the groups showed a clear pattern in northern hemisphere: increasing of the alkalinity in the humid and semihumid areas from the one side, and acidification in the more southern arid and semi-arid areas from the other side, that may indicate the presence of zonal trend.

Keywords: Transformation of soil cover · Soil organic carbon · pH · Data base · Soil-ecological regions

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1 Introduction

The Earth soil cover is an irreplaceable ecological basis of the biosphere functioning, humankind life and activity, since it is media for matter and energy complex exchange processes between the atmosphere, Earth's crust, hydrosphere and all living organisms. Now already half of the planets soil is under anthropogenic change [6, 7, 27]. One of the most important environmental problems facing our time is urbanization. Occupying slightly more than 1% of the land area, urban areas are located in practically all natural zones from sub-polar to equatorial latitudes [20]. Urban population growth in recent decades was so swift that the urban environment is no longer able to meet many of the biological and social needs of modern man [1, 26, 27].

Despite the fact that the transformation degree of an urban soil and its causes in the literature studied very well, but among a large number of publications dedicated to investigation of the soils properties in urban areas, there is virtually no research about impact level of natural areas conditions on soil properties. However, the question of interest is - if there is a trend in the, for example, pH and organic carbon distribution of the transformed urban soils. On the one hand, urbanization became the source of specific organic matter, which is unspecific for natural soils (municipal and household waste, atmospheric dust, soot, compost-based reclamation mixtures, etc.), which can lead to an increase in SOC stock. On the other hand, the natural organic substances flow is disturbed by the annual removal of plant litter, regular lawn mowing etc. [15, 24, 26]. Type of territory pollution can also affect the pH of urban soils and plant productivity in different ways [5, 15]. Thus, a high variation of soil properties is typical even for urban sites of similar land use [10, 13, 15, 17, 21]. So how close are the properties of urban soils of Murmansk (Russia), located north of the Arctic Circle and, for example, of Ibadan (Nigeria).

The aim of this study was a comparative analysis of the soil organic carbon (SOC) and the water-extracted pH of urban soils and natural (background) soil surrounding areas in different soil-bioclimatic belts and soil-ecological regions.

2 Methods

To solve this problem, the urban soil properties database was created, based on the analysis of scientific publications and our own data. The database stores soils upper horizon properties in urban areas of 138 cities around the world (Fig. 1). Cities grouping by soil-bioclimatic areas has been done in accordance with the Soil-Ecological Regions Map from Resources and Environment World Atlas (1998), scale 1:60 000 000. The urban soil properties database analysis revealed that cities are located in 14 different soil-ecological regions. Set of natural zonal soils was determined by the map FAO/UNESCO Soil Map of the World 1: 5 000 000 (2016) [8]. The SOC and pH values of background zonal soils were obtained from the Harmonized World Soil Database (HWSD) ver. 1.2 (2012). Maps were created with MapInfo Professional v. 12.5. The calculation of statistical parameters was carried out in Statistica v. 10.0.

Not only typical urban soils (Technosols) were included in the database of urban soil properties, but also slightly disturbed soils of urban forests, parks, lawns and green

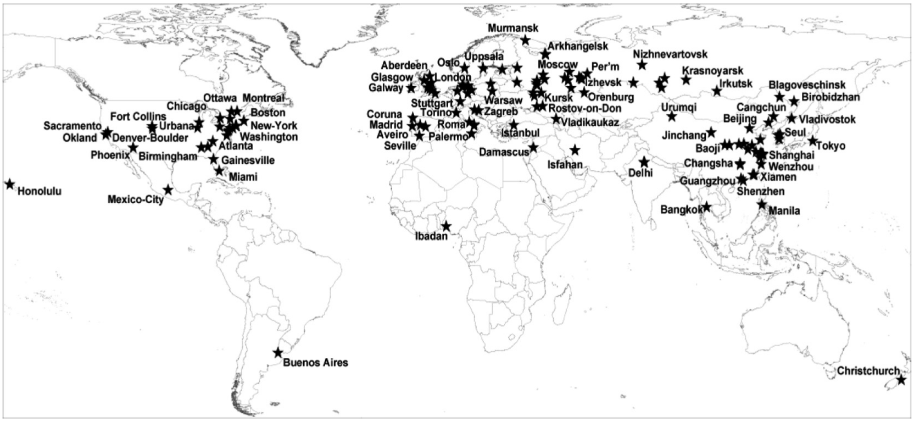


Fig. 1. Cities locations map from the urban soils database

areas intra building, located in different geomorphological positions inside the city, were included too.

Most of the cities included in the created database are situated in Russia [2, 3, 11, 30], USA [14, 19, 25], in Western European countries [4, 16, 18, 23] and in China [28, 32].

All the data, that were presented in the research were included in the database in the original units and the information of the territory land use. The base of properties was then supplemented with the GPS location of each city, soil-bioclimatic region, measurement methods and other important information, if it was mentioned in the original research. The each data has the full reference to the source.

As there were many different units, that are common in each country, the data on the carbon content needed to be converted to the general unit – SOC (% from Total C). The average value was calculated in the cases, when the several researches have been found.

To define a set of background zonal soils there was created special overlay layer between the cities and the soils of the world maps, then buffer zones of 10–15 km radius around the towns was drawn, depending on the size of the city. Soils that fall within the boundaries of the buffer zone were treated as typical. For each city there have been identified from one to three natural soils, including intrazonal alluvial and volcanic soils.

Besides that, each soil sample in urban cities within bioclimatic soil region and in each sample of natural soils, in areas identified by the buffer zones, the average values of SOC and pH were calculated. The preliminary conversion of logarithmic forms was produced in numeric to calculate the average pH, then the average value was recalculated and transformed in logarithmic.

In addition, the following statistical parameters: standard deviation, range, maximum and minimum values in the total sample and within groups, the difference between pH and SOC in the natural (background) soil and urban soils, the correlation coefficient of geographical coordinates of cities and the significance of the correlation coefficients, - were calculated for each sample in same soil – ecological region.

3 Results

The initial analysis of the literature has shown that there are virtually no complex researches that compare several urban soils and it's properties from different cities in the world. The few studies that have been found were comparing mainly heavy metal pollution, but not the natural features [9]. Most articles contained are data only for the topsoil (0–10 cm or 0–20 cm) with the indication of the territory land use and without any classification of the soil [9, 22, 28].

Cities that were selected in the database were divided into fifteen groups of soil-bioclimatic zones in accordance with the soil-ecological regions map from World Atlas Nature and Earth Resources (1998). The fifteen groups contains different number of cities: the sample size ranges from 1 to 21.

Analysis of the results shows that most of the cities is located in the Extrahumid Broad Forest Regions: a large area of the North and Central parts of Western Europe, the southern regions of the Pacific coast of Russia and North Atlantic areas of the U.S. and Canada. The second largest group are the cities of forest areas of the Humid Taiga - Forest regions. This group includes most cities of Russia. Territory of Semihumid Xerophytic Forest regions covers a large area in the South of Western Europe, and unites the cities in countries such as Spain, Portugal, Italy, Turkey. In China, area getting together the largest number of cities, was the area of Extrahumid Forest Region of the subtropical zone. Southern regions of arid, extra arid and desert regions, humid tropics and subtropics mostly weakly urbanized.

Statistical analysis showed that the SOC values range in the urban soils cities is much higher than in natural (background) soils (Table 1). This statement can be confirmed by earlier obtained data [24, 29].

This fact is a result of anthropogenic factors influence on the processes of reduction and accumulation of organic matter in the soil. In general, the difference is bigger in the more Northern regions, and gradually decreases to the South. To confirm the results obtained for the mean values, the dependence of the whole sample difference between SOC in urban and background soils from the latitude position of the city was investigated (Fig. 2).

The difference in organic matter content in urban soils compared to the background soils decreases in gradient from North to South. The difference in values are significantly correlated with latitude (correlation coefficient of 0.49 is significant).

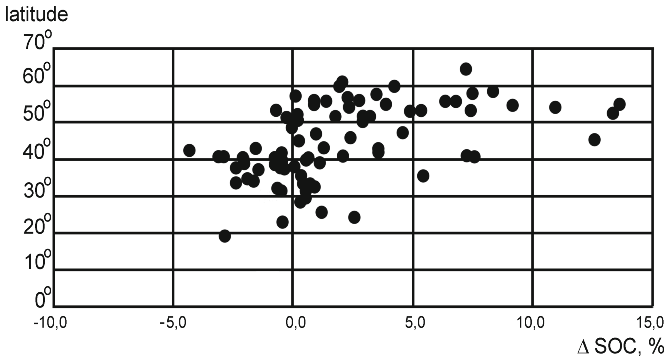
In order to clarify, whether the regularity is a manifestation of zoning, the average values of the carbon content within the selected groups were distributed in a square matrix by the climatic zoning and the climate humidity degree in accordance with the map of soil-ecological regions legend structure (Table 2).

A comparative analysis of matrixes for urban and natural soils have not shown any dependencies. This means that the characteristics of the SOC content in urban soils is not zonal. In this way, the earlier pattern, which shown the gradient of the carbon excess in urban soils in comparison with natural, is not due to the zonal and, probably, due to socio-economic and natural-historical factors.

In the same way, pH (water) was analyzed. In comparison of urban and natural soils average pH values, statistically significant differences were not observed (Table 3).

Table 1. Means, standard deviations and ranges of SOC (% from Total C) content for urban and natural (background) soils for soil-ecological regions

Soil-bioclimatical belts	Soil-ecological regions	Sampling size	Urban soils			Background soils		
			Mean	St. dev.	Range	Mean	St. dev.	Range
Boreal belt	Humid Taiga - forest regions	20	6.77	4.31	14.8	1.58	0.82	2.79
Subboreal belt	Semihumid forest - steppe regions	7	6.70	4.26	12.86	2.01	0.40	1.35
	Extrahumid broad forest regions	21	2.46	2.93	10.76	2.26	0.96	3.79
Subtropical belt	Semihumid Xerophytic forest regions	11	2.22	3.24	9.9	1.69	0.92	3.09
	Extrahumid forest region	5	1.55	1.18	2.55	1.25	0.43	1.19
	Semiarid bush - steppe regions	4	1.71	3.60	3.13	1.30	0.92	1.82



ΔSOC – the difference in carbon content between urban and background soils

Fig. 2. The dependence of the carbon content increment in urban soils from the city's latitude (Northern hemisphere)

However, a comparison of the maximum values of the urban and natural soils reveals increasing alkalinity in the following areas: humid taiga-forest, forest-steppe semi-ramide, extragenic forests of the subtropics and the Mediterranean region semihumid dry forests. The data of the following regions contains 2/3 of all values for urban soils. This implies that urban soils, compared to natural, in most cases have a more alkaline reaction medium.

For results verification, dependence of the difference between the pH values in urban and natural soils from the city location latitude was also studied (Fig. 3). The analysis showed that the correlation coefficient is 0.45, which is significant. Thus

Table 2. The distribution of the SOC (% from Total C) content average values for soil-ecological regions considering climate and facies

Soil-bioclimatic belts	Moisture regions					
	Extra-humid	Humid	Semi-humid	Semiarid	Arid	Extra-arid
Urban soils						
Boreal belt	No data	6.77	3.98	–	–	–
Subboreal belt	2.46	No data	6.70	5.63	No data	No data
Subtropical belt	1.55	3.04	2.22	1.71	No data	1.40
Tropical belt	No data	2.46	0.12	No data	No data	No data
Background soils						
Boreal belt	–	1.58	2.43	–	–	–
Subboreal belt	2.26	–	2.01	1.57	–	–
Subtropical belt	1.25	1.86	1.69	1.30	–	0.75
Tropical belt	–	1.72	2.98	–	–	–

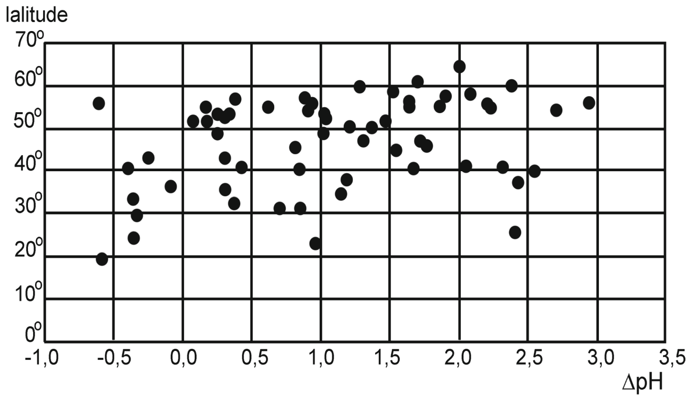
Table 3. Means, standard deviations and ranges of pH (water) values for urban and natural (background) soils for soil-ecological regions

Soil-bioclimatical belts	Soil-ecological regions	Sampling size	Urban soils		Background soils	
			Mean	Range	Mean	Range
Boreal belt	Humid Taiga - forest regions	20	5.87	2.95	5.02	2.2
Subboreal belt	Semihumid forest - steppe regions	8	7.21	1.9	6.78	0.51
	Extrahumid broad forest regions	7	5.19	3.25	5.35	1.84
Subtropical belt	Semihumid Xerophytic forest regions	8	6.95	1.45	5.36	1.52
	Extrahumid forest region	4	6.85	0.48	6.08	1.54
	Semiarid bush - steppe regions	7	5.19	3.25	5.35	1.84

confirmed the dependence obtained from the analysis of maximum values of pH in regions: urban soils have a more alkaline environment than in natural conditions.

Despite the fact that the anthropogenic factor significantly affects urban soil, bringing together the values of cities soils acidity in Northern and more Southern latitudes, we can clearly trace some zonal trend (Table 4).

In humid and semihumid regions the pH value of the aqueous extract in urban soils increase from acidic to slightly alkaline range from the tropical belt to the boreal belt. In the range from extra humic to extra arid there is a clear pattern of mean values both for urban and natural soils. In the boreal zone pH decreases from humid regions to arid one. In the subtropical belt, the acidity decreases when moving from humid to arid regions. There are not enough values to estimate patterns in the tropical belt, but the same trend as in the subtropics can be observed.



ΔpH – the difference between the pH values (aqueous extract) of city and background soils

Fig. 3. The dependence of the increment of pH (aqueous extract) in urban soils from the city's latitude (Northern hemisphere).

Table 4. The distribution of the pH average values for soil-ecological regions considering climate and facies

Soil-bioclimatic belts	Moisture regions					
	Extra-humid	Humid	Semi-humid	Semiarid	Arid	Extra-arid
Urban soils						
Boreal belt	No data	5.87	7.90	–	–	–
Subboreal belt	5.19	No data	7.94	6.30	No data	No data
Subtropical belt	6.85	5.38	6.95	7.38	No data	7.46
Tropical belt	No data	4.60	5.20	No data	No data	No data
Background soils						
Boreal belt	–	5.02	4.97	–	–	–
Subboreal belt	5.35	–	7.00	6.44	–	–
Subtropical belt	6.08	5.30	5.36	6.07	–	7.48
Tropical belt	–	5.00	5.79	–	–	–

4 Conclusions

In urban soils the average carbon content is higher than in natural soils. There is a Northern gradient of the carbon excess in urban soils in comparison with natural one, however, this pattern is probably not zoned, and, apparently, has a socio-economic nature. On the one hand, natural (background) soils of boreal belt (Podzols, Albeluvisols, Cambisols) and extrahumid broad forest regions of subboreal belt (Cambisols) have a low content of SOC. On the other hand, these regions account biggest part of the historical towns and megapolises of Europe, Russia, USA and Canada, characterized by high contents of SOC.

In urban soils the average pH value is not statistically significantly different from the corresponding values in natural soils. However, while comparing the respective maximum values there is a pattern of more alkaline environment of urban soils in comparison with natural one appeared. The gradient of increasing alkalinity of urban soils in comparison with natural soils from South to North forms a trend of convergence on the level of soil acidity cities located in different climatic zones, reflecting the influence of anthropogenic factor.

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References

1. Agarkova, M.G.: Ecological and genetic characteristics of urban soils ecosystems (by the example of the Leninsky district of Moscow). Abstract of the Ph.D. thesis. Biol. Sci. 03.00.27. Moscow (1991). (in Russian)
2. Alexandrova, A.B.: Soil-ecological conditions of landscapes formation of Kazan. Abstract of the Ph.D. thesis. Biol. Sci. 03.00.16. Kazan (2004). (in Russian)
3. Baboshkina, S.V., Puzanov, A.V.: Chemical composition of soils and plants of various anthropogenic territories, Barnaul. world Sci. Cult. Edu. **3**, 14–18 (2008). (in Russian)
4. Beesley, L., Dicknson, N.: Carbon and trace element mobility in an urban soil amended with green waste compost. J. Soils Sediments **10**, 215–222 (2010). https://doi.org/10.1007/s11368-009-0112-y
5. Churkina, G.: Modeling the carbon cycle of urban systems. Ecol. Model. **216**, 107–113 (2008). https://doi.org/10.1016/j.ecolmodel.2008.03.006
6. Dobrovol'skiy, G.V.: Soil degradation – a threat to global economic crisis. Age Globalization **2**, 54–65 (2008)
7. Dobrovolskiy, G.V.: The place and role of soil in the biosphere and human life. Bull. Use Prot. Nat. Res. Russ. **2**, 23–27 (2011)
8. FAO/UNESCO Soil Map of the World. Scale 1:5 000 000 (2016). http://www.fao.org/soils-portal/soil-survey/en/
9. Guitao, S., Zhenlou, C., Shiyuan, X., Ju, Z., Li, W., Chunjuan, B., Jiyan, T.: Potentially toxic metal contamination of urban soils and roadside dust in Shanghai, China. Environ. Pollut. **156**, 251–260 (2008). https://doi.org/10.1016/j.envpol.2008.02.027
10. Godwin, C., Chen, G., Singh, K.K.: The impact of urban residential development patterns on forest carbon density: an integration of LiDAR, aerial photography and field mensuration. Landsc. Urban Plann. **136**, 97–109 (2015). https://doi.org/10.1016/j.landurbplan.2014.12.007
11. Gorbov, S.N.: Soil of urbolandscape of rostov-on-don, their ecological status and evaluation of pollution. Abstract of the Ph.D. thesis. Biol. Sci. 03.00.27. Rostov-on-Don (2002). (in Russian)
12. Harmonized World Soil Database (version 1.2). FAO, Rome, Italy and IIASA, Laxenburg, Austria. FAO/IIASA/ISRIC/ISS-CAS/JRC (2012). http://www.fao.org/soils-portal/soil-survey/en/

13. Bae, J., Ryu, Y.: Land use and land cover changes explain spatial and temporal variations of the soil organic carbon stocks in a constructed urban park. Landsc. Urban Plann. **136**, 57–67 (2014). https://doi.org/10.1016/j.landurbplan.2014.11.015
14. Kaye, J.P., McCulley, R.L., Burke, I.C.: Carbon fluxes, nitrogen cycling, and soil microbial communities in adjacent urban, native and agricultural ecosystems. Glob. Change Biol. **11**, 575–587 (2005). https://doi.org/10.1111/j.1365-2486.2005.00921.x
15. Lehmann, A., Stahr, K.: Nature and significance of anthropogenic urban soils. J. Soils Sediments **7**, 247–260 (2007). https://doi.org/10.1065/jss2007.06.235
16. Lorenz, K., Kaundler, E.: Biochemical characterization of urban soil profiles from Stuttgart, Germany. Soil Biol. Biochem. **37**, 1373–1385 (2005). https://doi.org/10.1016/j.soilbio.2004.12.009
17. Lorenz, K., Lal, R.: Biogeochemical C and N cycles in urban soils. Environ. Int. **35**, 1–8 (2009). https://doi.org/10.1016/j.envint.2008.05.006
18. Papa, S., Bartoli, G., Pellegrino, A., Fioretto, A.: Microbial activities and trace element contents in an urban soil. Environ. Monit. Asses. **165**, 193–203 (2010). https://doi.org/10.1007/s10661-009-0938-1
19. Pavao-Zucherman, M.A.: The nature of urban soils and their pole in ecoligical restoration in cities. Restor. Ecol. **16**, 642–649 (2008). https://doi.org/10.1111/j.1526-100X.2008.00486.x
20. Pouyat, R., Groffman, P., Yesilonis, I., Hernandez, L.: Soil carbon pools and fluxes in urban ecosystems. Environ. Pollut. **116**, 107–118 (2002). https://doi.org/10.1016/S0269-7491(01)00263-9
21. Raciti, S.M., Groffman, P.M., Jenkins, J.C., Pouyat, R.V., Fahey, T.J., Pickett, S.T.A., Cadenasso, M.L.: Accumulation of carbon and nitrogen in residential soils with different land-use histories ecosystems **14**, 287–297 (2011). https://doi.org/10.1007/s10021-010-9409-3
22. Rawlins, B.G., Vane, C.H., Kim, A.W., Tye, A.M., Kemp, S.J., Bellamy, P.H.: Methods for estimating types of soil organic carbon and their application to surveys of UK urban areas. Soil Use Manag. **24**, 47–59 (2008). https://doi.org/10.1111/j.1475-2743.2007.00132.x
23. Rodriguesa, S., Pereiraa, M.E., Duartea, A.C., Ajmone-Marsanf, F., Davidsonc, C.M., Grčmand, H., Hossackb, I., Hursthouseb, A.S., Ljungg, K., Martinif, C., Otabbongg, E., Reinosoe, R., Ruiz-Cortése, E., Urquhartc, G.J., Vrščaj, B.: Mercury in urban soils: a comparison of local spatial variability in six European cities. Sci. Total Enviro. **368**, 926–936 (2006). https://doi.org/10.1016/j.scitotenv.2006.04.008
24. Rozanova, M.S., Prokof'eva, T.V., Lysak, L.V., Rakhleeva, A.A.: Soil organic matter in the Moscow state university botanical garden on the Vorob'evy hills. Eurasian Soil Sci. **49**, 1013–1025 (2016). https://doi.org/10.1134/S106422931609012X
25. Schindelbecka, R.R., van Esa, H.M., Abawib, G.S., Wolfec, D.W., Whitlowc, T.L., Guginob, B.K., Idowua, O.J., Moebius-Clune, B.N.: Comprehensive assessment of soil quality for landscape and urban management. Landsc. Urban Plann. **88**, 73–80 (2008). https://doi.org/10.1016/j.landurbplan.2008.08.006
26. Stroganova, M., Miagkova, A., Prokofieva, T., Skvortsova, I.: Soils of Moscow and Urban Environment. PAIMS, Moscow (1998)
27. Stroganova, M.N.: Urban soils: genesis. Systematics and environmental significance (by the example of Moscow). Thesis of doctor of biological sciences. Moscow (1998)
28. Sun, Y., Ma, J., Li, C.: Content and densities of soil organic carbon in urban soil in different function districts of Kaifeng. J. Geograph. Sci. **20**, 148–156 (2010). https://doi.org/10.1007/s11442-010-0148-3
29. Vasenev, V.I., Prokof'eva, T.V., Makarov, O.A.: The development of approaches to assess the soil organic carbon pools in megapolises and small settlements. Eurasian Soil Sci. **6**, 685–696 (2013). https://doi.org/10.1134/S1064229313060100

30. Voyt'uk, E.A.: Accumulation of heavy metals in soil and plants in the urban environment (on the example of Moscow). Abstract of the Ph.D. thesis. Biol. Sci. 03.02.08. Ulan-Ude (2011). (in Russian)
31. World Atlas: Resources and Environment. I, II. Vienna: Ed.Hoelzel; IG RAS, Moscow (1998)
32. Zhang, J., Pu, L., Peng, B., Gao, Z.: The impact of urban land expansion on soil quality in rapidly urbanizing regions in China: Kunshan as a case study. Environ. Geochem. Health **33**, 125–135 (2011). https://doi.org/10.1007/s10653-010-9326-6