Study on soil quality in different functional zones of Sofia region

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Abstract

The present study deals with examining the condition of urban soils and their potential to deliver soil-related regulating ecosystem services concerning the level of anthropogenic pressure in different functional zones of Sofia, Bulgaria. Analyses of data for selected characteristics of superficial 0-10 cm soil layer of urban soils were performed. Soils were sampled from 30 experimental plots within a geo-referred network covering urban and peri-urban territories. The concentrations of heavy metals Cu, Zn, Pb and Fe were analysed to determine the level of pollution, while soil pH, cation-exchange capacity (CEC), total carbon and total nitrogen content were used as indicators for assessing the regulating ecosystem service "soil quality". The results demonstrate the differences in the potential of four functional zones – green zones, industrial zones, residential zones and zones for urban agriculture, to regulate and maintain "soil quality". The purpose of the assessment is to outline the zones with the potential for implicating mitigation measures in urban and peri-urban zones, based on maps of soil quality, which contributes to focusing more attention on the protection and restoration of urban soils, to reduce soil pollution and to increase the reuse of urban soils.

Keywords

soils, anthropogenic pressure, urban ecology, assessment, spatial analysis, maps

Introduction

Nowadays, cities continue to evolve and grow in size, complexity and in significance. The continuous concentration of people in the urban formations provokes scientists' attention, broadening the interest towards integration of newly-developed concepts within the urban management, planning and protection of natural resources. Connecting the elements and considering the constant mutual interaction between the city and nature gives birth to the notion of urban ecosystems. As Oke et al. (2017) pointed out, urban ecosystems are formed by the biological population of organisms (vegetation, animals, people) and the abiotic environment in cities. Today, urban areas are facing enormous challenges, such as climate change (Pouyat 2020), demographic aging and natural resource depletion (Haase et al. 2014). The presence of people creates interrelated socio-ecological systems, which provide a wide range of services – cultural, regulating, provisioning and supporting the habitat. Regulating services maintain functions, such as air and soil quality and flood, stormwater and disease control (Gomez-Baggethun et al. 2013). In general, locally-generated ecosystem services have substantial impacts on the quality of life in urban areas and should, therefore, be more explicitly addressed in conceiving strategies aimed at sustainable development, livability and resilience in urban milieu. Residents of cities, workers in institutions and organisations and ecologists all can benefit from a better understanding that cities are ecosystems and to use information about the condition of their components to solve problems and to outline further development steps (Berkovits et al. 2003).

Soils are the fundamental component of terrestrial ecosystems and are widely distributed, easily accessible and easily wasted (de Groot 1992.) The specifics of urban soils (Panico et al. 2018) define their place as the basic component which determines the provisioning of many ecosystem services in urbanised territories. Therefore, soil quality has a high potential to play the role of a critical starting point in establishing a healthy balance in the urban environment. Delineating the soil-related services and documenting their relative significance in given regions is of a critical importance (Baveye and Gowdy 2016). Different levels of anthropogenic pressure together with the overall effect of climatic changes affect urban soils and cause variations in the potential of urban ecosystems to provide services. Soils are under serious threat, especially in urban areas, where anthropogenic pressure is much higher. With rapid urbanisation and with the increasing use of fertilisers and pesticides in urban agricultural land use, soil heavy metal pollution has become an urgent environmental concern (Parr et al. 1992,Luo et al. 2012).

The concept of soil quality is considered to transcend the productivity of soils (Larson and Pierce 1991,Parr et al. 1992) to explicitly include the interactions between humans and soil and to encompass ecosystem sustainability as the basis for the benefits that humans derive from soils. A critical review of soil quality focusing on indicators under agricultural land use and assessment approaches is provided by Bunemann et al. (2018) who underlines that, beyond scientists, those who have an immediate stake in soil quality are land managers, i.e. urban green areas and the public at large. Soil plays a crucial role in ecosystem functioning, but the main studies are focused on their provisioning and regulating ecosystem services, relating to soil physico-chemical properties (Adhikari and Hartemink 2016). The multi-functionalities of soils and their vastly different chemical, physical and biological properties urge scientists to elaborate operational methods for quantifying the contributions of soils to the supply of ecosystem services (Greiner et al. 2017). Research on soil quality concerning ecosystem services has been an important scientific topic in Bulgaria as well. Soil is considered a key component in mapping ecosystem services in Bulgaria (Nedkov et al. 2018) and it is recognised as an important parameter in the Methodology for assessment and mapping of urban ecosystems condition and their services in Bulgaria (Zhiyanski et al. 2017).

Following the recent tendencies of ecological studies in urban environments, the present study deals with examining soil quality in the region of Sofia within the context of assessment and mapping the potential of urban ecosystems to provide the regulating ecosystem service “soil quality”. The territory of interest is divided into four functional zones - green zones, industrial zones, residential zones and zones for urban agriculture, following the existing studies of urban ecosystem services (Zhiyanski et al. 2017, Nedkov et al. 2017, Dimitrov et al. 2018) and tailored to the concept of the study. The assessment relates to outlining the functional zones with the potential for implication of measures for mitigation of soil pollution in urban and peri-urban territories. This could provide a good information base for decision-makers and urban planners for policies, targetting protection and restoration of urban soils, as well as reduction of soil pollution and an increase in the reuse of urban soils.

Materials and methods

Sofia is located in the Sofia Valley at the foot of the Vitosha Mountain in the western parts of Bulgaria and, within its administrative borders, it covers an area of 492 km² (National Statistical Institute 2015). The territory includes the main settlement and peri-urban areas, which are under conversion and/or used for urban agriculture. A multidisciplinary approach that combines collection and analyses of quantitative data for selected indicators and further integration of mapping by using geospatial analysis and the possibilities of the geoinformation systems for spatial reference and interpolation of data is applied. In the process of urban anthropogenesis, natural soils in the region were transformed in urban conditions to the state of Urbic Technosols (Clayic) and Urbic Anthrosols (Clayic) (Food and agriculture organization of the United Nations 2014). They differ in the morphology of the soil profile and humus content, but are characterised by similar acid-alkali properties (Zhiyanski et al. 2011). The territory of Sofia is conditionally divided into zones, based on the Typology of urban ecosystems in Bulgaria (Dimitrov et al. 2018). These zones are consolidated into three specific types of functions - residential, green and industrial zone and supplemented by one zone in the peri-urban territory that covers the urban agriculture function (Urban Atlas, Copernicus Land Monitoring Service 2018). The study relates the functions of the territory, represented by these four basic, but very distinct zones, with the soil quality, looking for patterns of the spatial distribution of pH, soil carbon content, total nitrogen, cation-exchange capacity (CEC) and level of pollution with heavy metals in soil. These parameters are used as indicators for the potential of functional zones to provide regulating services concerning the level of anthropogenic pressure.

Soil sampling method

The ICP Forest Level I 2020 forest ecosystem network (16 x 16 km) was downsized to a 3 x 3 km cell and used as a base to distribute the experimental plots within the city and over its peri-urban territory. Each experimental plot covers an area of 0.1 ha and is affiliated with a specific functional zone, described in detail in the following Geospatial Analysis section.

The soil sampling was realised in 2011 on the territory of Sofia region covering the city and its surroundings. The soil samples were collected by coring in five points for each experimental plot in three soil depths: 0-10; 10-30; and 30-50 cm, but, in the present study, only the superficial soil layer is discussed. Although heavy metal content in soils could be related to soil parent material composition, the contribution from anthropogenic sources affects superficial soil layers; therefore, the determination of heavy metals content was focused on the superficial soil (0-10 cm depth) as the indicator for anthropogenic pressure effect on soil condition.

The soil samples were analysed for textural composition (pipette method titration with hydrochloric acid - HCl), pH (potentiometrically), carbon content (Corg.) according to the Turin method, for total nitrogen (N) according to Kjeldahl and cation-exchange capacity (CEC) according to Chuljian (1978). The content of heavy metals in the soil was determined after treatment with nitric acid: hydrochloric acid - HNO_3:HCl, 1:3 (ISO 1146). The metal concentrations in the extract were determined by atomic absorption spectrophotometry (AAS).

The grid with the experimental plots and the results from the samples provide information about the condition of urban soils in different functional zones (Fig. 1).

Geospatial analysis

To distribute the data from the soil sampling and relate it to data for the ecosystem service "soil quality", provided by the functional zones, the possibilities of the geographic information systems (GIS) for spatial reference and interpolation were used. The combination of data different in their genesis and characteristics provide opportunities for solving different types of research problems (Todorov and Kirilov 2022). GIS is particularly useful for mapping and assessing the value of ecosystem services in different contexts. GIS have been used to map the ecosystem services, provided by soils, across space using indicators, the ecological production function approach, in which detailed information is used to map different ecosystem services and underlying processes affecting those services in an area and the benefits-transfer approach, in which ecosystem service values from one area are transferred to the same ecosystems in other areas (Nemec and Raudsepp-Hearne 2012). Using that approach, the indicators of soil quality are mapped with respect to the Methodology for assessment and mapping of urban ecosystems condition and their services in Bulgaria (Zhiyanski et al. 2017) which is based on the corresponding EUNIS classification on level 2 (European Environment Agency 2021) combined with the National Concept for Spatial Planning on level 3 (National concept for spatial development 2013) and are proposed for detailed typology as level 3 to outline 10 urban sub-types. The sub-types were generalised into three zones according to the main functions of the urban territory and considering different land use, land cover, soil sealing, pollution and anthropogenic influence. The residential zone includes residential areas with different densities, green areas include all park territories and industrial areas as shown in

Fig. 2. To include the peri-urban territory in the soil parameters analysis, an additional zone that is not covered in the EUNIS classification - urban agriculture, was included. To define this area, the Urban Atlas, Copernicus Land Monitoring Service (2018) was used, selecting only the arable land on the outskirts of Sofia. Combining these datasets gave an insight into the interdependencies that exist (or not) between the soil quality and the functions of the territory. To outline the relationship between functional zones and the ecosystem services concept applied at national level, the sub-types of urban ecosystems defined by the Methodology for assessment and mapping of urban ecosystems condition and their services in Bulgaria (Zhiyanski et al. 2017) are generalised. (Fig. 2):

The territory of Sofia region is, thus, differentiated in these four functional zones and each of them is attributed to the scores obtained for the soil quality. Interpolation was applied for matching the range of the terrain data with the range of the functional areas. The Inverse Distance Weighted (IDW) technique was used to compute an average value for unsampled locations, based on values from nearby weighted locations. The weights are proportional to the proximity of the sampled points to the unsampled location and can be specified by the IDW power coefficient (Gimond 2022). Tuncay et al. (2016) estimate IDW interpolation on spatial variability of selected soil properties and show that the interpolation results are consistent with the soil analysis results, thus enabling the extension of the obtained values to any similar non-sampled region. Robinson and Metternicht (2006) tested the performance of spatial interpolation techniques for mapping soil properties. In all uses of IDW, the power of one was the best choice, which may be due to the low skewness of the soil properties interpolated. That is why the IDW interpolation was done with the power of one for all the parameters, setting the environment's extent to the range of the functional zones. As an output, a separate raster layer that contains the distribution of the values of each parameter is generated. This raster is related to the polygon file of the functional zones. The values of the parameters are then calculated by zones. The spatial patterns of the accumulation of heavy metals related to the functions of the territory are obtained. Maps that visualise the accumulation of heavy metals in the soils in Sofia distributed by functional zones are generated.

Specific features of chemical soil properties in urban areas are contamination with heavy metals and alkalisation (Craul 1999, Yang et al. 2014). As indicators for the level of anthropogenic pressure in functional zones, the following indicators are used: the concentrations of heavy metals Cu, Zn, Pb and Fe, which are the main pollutants in the urban environment of Sofia, while soil quality is assessed by pH, total carbon (C) content, total nitrogen (N) and the cation-exchange capacity (CEC). The indicators are assessed in five categories associated with different scores from 1 to 5 (Table 1):

The assessment of each indicator was therefore summed and the mean value is used in populating the matrix for the needs and supply of ecosystem services, suggested by Burkhard (2018) and supplementing it with separate evaluation for the soil quality (reflecting the mean score on indicators pH, CEC, N and C), while the evaluation of the level of anthropogenic pressure reflects the evaluations of the accumulation of heavy metals. The matrix is presented in Table 2 and has the following structure (Table 2):

The indicators are evaluated in a scale from 1 to 5, where 1 shows the worst assessment that the indicator receives. The values of the indicators are classified in five equal intervals. These values are also juxtaposed to the Safety concentrations and Maximum permissible concentrations as regulated in Regulation No. 3 (Ministry of Agriculture 2008) on the standards for permissible content of harmful substances in soils. By using the spatial analysis Zonal Statistics, a cross-reference between the evaluation of the soil potential and the functional zones is provided.

Results

The results from the present study show no exceedance of the safety concentrations and the Maximum permissible concentrations as regulated in Regulation No. 3 for Cu and Zn. The results obtained for the sampled soils show exceedance of the permissible concentration (45 mg/kg) for Pb for 24 out of the 30 experimental plots and four of them are on the verge of the Maximum permissible concentrations of 130 mg/kg.

Anthropogenic pressure

To determine the level of anthropogenic pressure on soils in the studied functional zones, the results for heavy metals concentrations were differentiated and interpolated by using IDW interpolation and dissemination of the outcome by functional zones that include the green zone, industrial zone, residential zone and urban agriculture. The scores of indicators for anthropogenic pressure are visualised as consolidated results for each of the heavy metals, including data for the main soil pollutants as determined in the Environmental analysis in the Programme for Sofia (Sofiaplan, Sofia Municipality (2021)) and data for the transport network and power plants in Sofia, which are the main sources of air pollutants (Table 3).

The intervals correspond to the maximum permissible concentration of the heavy metals acceding to Regulation No. 3 on the standards for permissible content of harmful substances in soils (Ministry of Agriculture 2008). All concentrations above these values are assessed as “1-Very high”.

Copper (Cu) could influence the fertility of the soil. Cu is not particularly mobile in the soil and only a small part of this element is absorbed by plants. The natural behaviour of copper in soils is to be concentrated in the surface due to its tendency to complex with organic matter (Chuljian 1978). The values of the samples are below the safety concentrations of 60 mg/kg. The lowest value of 9.34 mg/kg is detected in the industrial zone and highest accumulation in the residential zones. In the green zones, the values are in the interval 20-25 mg/kg which indicated low and very low level of pollution and anthropogenic pressure, respectively. From a spatial point of view, the concentrations are higher in north-western Sofia, which may be in relation to the underlying geology considering the determined high concentration in the deeper layers (Ballabio et al. 2018), (Fig. 3).

The concentration of iron (Fe) varied from 10270 mg/kg to 29650 mg/kg. The highest concentration is detected in the residential territories and the lowest – in the industrial and green zones, but the range of the values is small. The values of this indicator vary from high to low in all the functional zones and no clear pattern of distribution could be determined. The range of concentration values indicates a relatively low level of pollution with iron in the studied region. It could be summarised that the iron content in the superficial urban soil layer is within the limits and without exceedance of safety concentrations (Fig. 4).

The values for accumulation of Lead (Pb) range from 35 mg/kg to 130 mg/kg, which exceeds the safety concentrations of 45 mg/kg and is on the verge of the Maximum permissible concentrations. Only limited territories for urban agriculture show lower accumulation of Pb. Therefore, Pb appears to be defined as one of the main pollutants in urban soils in Sofia and needs special attention (Fig. 5).

The accumulation of zinc (Zn) varies from 52 to 130 mg/kg, keeping it below the safety concentrations, but still with predominantly high values. All the functional zones include both minimum and maximum values. No specific pattern could be determined for the distribution of that indicator. The peri-urban territories that are designated for urban agriculture show lower values of Zn accumulation, except for two locations, which are situated directly next to the industrial zones (Fig. 6).

Soil quality

To complete the research task, the relationship between the functional zone and the indicators for soil quality was also investigated.

The evaluation of the indicators of soil quality is based on scoring their values, including C, N and pH and CEC, following the matrix presented in Table 4 and disseminating the results into equal intervals that are evaluated with grades from 1 (very bad) to 5 (very good) (Table 4).

The intervals were used to assess the dissemination of the indicators in the territory of Sofia region.

Acidity (pH) of studied urban soils varied from 6.37 to 8.41, which refer to the neutral-alkaline soils. pH plays an important role in the stabilisation of organic matter. Furthermore, total heavy metal concentrations in the soil correlate positively with pH. This correlation is highly specific for every metal compound and highly influenced by the existence of oxygen, organic matter and soil textural fractions (especially clay minerals) (Sintorini et al. 2021). The pH is higher in the south-eastern part of Sofia, where the soils are more alkaline (Fig. 7).

The carbon content in studied urban soils is low to very low compared to the surrounding natural soils. The lowest concentration of C is observed in the eastern part of Sofia. The peri-urban territories are distinguished by the highest concentrations. In the urban territory, the green zones and the residential zones share similar values for this parameter (Fig. 8).

CEC is a useful indicator for soil fertility and, in experimental plots, it varies from 27.71 to 56.4 meq/100g. Soils, having a high CEC, change pH much more slowly. CEC is linked to the organic carbon content, clay content and type of land-use and management. Again, there is a tendency for lower values in the eastern part of Sofia and values over 30 meq/100g in the peri-urban territory are confirmed (Fig. 9).

The pattern of distribution of the total nitrogen is very like the pattern of distribution of carbon, nitrogen, CEC and soils with higher pH. For all parameters, characterising the soil quality, the same geographical pattern of poor characteristics to the east and good in the peri-urban territory is observed. The distribution within the four functional zones has no clearly defined spatial pattern (Fig. 10).

The simple matrix was completed to assess the potential of urban functional zones to sustain "soil quality". The evaluation of each parameter by zone was summed and the mean value of the soil quality was aggregated. The results are presented in Table 5.

The soil quality parameters in the urban zone show rather 'bad' soil quality in the residential and industrial zone, medium potential in green zones and good potential in zones for urban agriculture. As visible from the maps, the eastern regions show lower quality (Table 6).

The anthropogenic pressure is assessed as medium in all functional zones, which demonstrates the effect of pollution on the overall urbanised region of Sofia including both urban and peri-urban territories. The scores for concentrations of Pb are poor and reduce the general score leading to worse overall evaluation.

A parallel between the soil quality and the condition of functional zones in terms of the anthropogenic pressure effect could be drawn. Green zones and urban agriculture zones have better overall evaluation than the residential and industrial zones and still have medium to good potential to sustain soil quality. It could be underlined that the demarcation is minimal and the scores have close values. The assessment shows that the soil quality is well provided by green zones and urban agricultural zones. Considering the overall anthropogenic pressure and the observed geographical patterns in the studied region of Sofia, the green infrastructure and peri-urban zones have the potential to contribute to a better condition of the soils through improvement of the main soil parameters.

Considering the assessment of the functional zones in Sofia, better potential in maintaining soil quality is determined for green zones and zones for urban agriculture versus residential and industrial zones, which are characterised by low potential.

Discussion

Good management of soils is fundamental in providing economic, socio-cultural and environmental benefits for the population and all communities in urbanised areas. According to the Common International Classification of Ecosystem Services, v.5.1 (2018) , one of the main ecosystem services that soils provide under code 2.2.4.1 Soil quality by weathering processes, part of the Biotic regulation and maintenance services which is part of class Weathering processes and their effect on soil quality in the group Regulation of soil quality. In addition, these services include flood mitigation, buffering the urban heat island effect, capturing air pollution, physical support for infrastructure, urban food growing and access to greenspace for mental and physical health; whilst at local and global scales, they contribute to nutrient cycling and carbon (C) storage (O'Riordan et al. 2021).

Urban soils are one of the dynamically changing factors, which directly relate to the other components of ecosystems and are characterised by a high adsorbing and accumulating effect in terms of both pollutants (Parr et al. 1992,Gencheva 2006). The specifics of the urban environment suggest different dynamics for the processes within soil and the distribution of substances that might influence soil quality in the long term. One of the specific problems in this regard is the contamination with heavy metals. In Bulgaria, assessments and analyses related to the horizontal and vertical distribution of heavy metals in the parks in the city of Sofia have been made by several authors (Bratanova-Doncheva 1988, Mankova 1989, Doichinova 2006). Heavy metals contamination has been reported, especially in plantations located near highways, while less pollution is observed in urban green parks (Doichinova 2006). The content of soil organic matter is a factor in the profile distribution of heavy metals. There is evidence of an inverse relationship - the accumulation of heavy metals in the soil and in the dead forest floor under forest plantations can affect its enrichment with organic matter due to the inhibition of some enzymes and the delay in microbiological processes for the demineralisation of hard-to-decompose organic waste (Li et al. 2009); therefore, pollution affects soil quality.

For the studied heavy metals (Cu, Zn, Pb, Fe), anthropogenic sources play a more important role in the global geochemical cycle of these elements than natural sources (Bertine and Goldberg 1972, Nriagu 1989). Artamonov (1986) reported that 8.3 times more Pb, 8.8 times more Cd, 7.2 times more Zn of anthropogenic origin than natural sources are released into the atmosphere. Atmospheric pollution is also the main source of soil contamination with heavy metals in areas with increased anthropogenic activity, such as urbanised areas (Guvenc et al. 2003). In cities and peri-urban areas where atmospheric pollution is observed, wet and dry deposition of heavy metals over the years leads to the enrichment of surface soil layers (Weiss et al. 1994,Yay 1998, Weiss et al. 1994). Soil mechanical composition also matters. The soil samples show a predominantly sandy composition, with 14.5-31.9% clay fractions. However, there are studies that show a direct relationship between the concentration of metals in the surface soil layers and the density of the population in cities and road transport (Yay 1998). It is proven that heavy metals - Pb, Zn, Cu and Cd are predominant pollutants in the urban environment and can be considered indicators of anthropogenic pollution (Nriagu 1989). These metals are major soil pollutants in gasoline, motor oil and industrial pollutants (Alloway 1995).

The results obtained for the accumulation of copper, zinc, lead and iron in the superficial soil layers in selected experimental plots in Sofia region confirm these findings and the negative effect of anthropogenic pressure on soils in ecosystems from all functional zones. As a result, it could be summarised that no specific pattern for the concentration of toxic metals in the urban territory has been determined, dependent on the functional zonation. Most of the indicators vary in the same range, regardless of whether they are in the residential, industrial or green zone. This brings us to the notion that green infrastructure is already affected by anthropogenic pressure and is threatened by difficulties maintaining the balance for a healthy ecosystem in the future. A trend that could be determined is that there is a ubiquitous concentration of Pb and Zn in the superficial soil layer which indicates contamination from anthropogenic activity. A possible reason for that circumstance may be that the local contamination from quarries and metallurgy from the past has spread over time and continue to cause ecological problems. This is a problem that needs attention and comparative studies.

Conclusions

The soil component is a very sensitive reflector of the condition of the urban ecosystem, as it is the backbone of many of the processes that keep its functionality. The quality of the soils in the functional zones in Sofia region determines the delivery of soil-related ecosystem services. The historical contamination of urban soils in Sofia originates from the anthropogenic activities related to intensive urbanisation combined with heavy industry, transport and local heating. Nowadays, the pressure on the urban ecosystems is still high compared to the natural territories; therefore, urban green zones play a significant role in provisioning a set of ecosystem services for the local population. The analyses of the parameters of soil quality in Sofia region show that the current condition in the green zones ensures the potential to supply ecosystem services, which is relatively higher than the potential in residential and industrial functional zones, but not so well expressed. Thus, the anthropogenic pressure over green spaces has already affected, to some extent, the capacity of urban forest parks to maintain good “soil quality” and functioning of ecosystems. On the contrary, the peri-urban areas used for urban agriculture still have a higher potential to supply good soil quality and could be used effectively. Considering that the anthropogenic pressure has a constant upward trend and that the negative consequences accumulate over time, the management of urban green zones faces the risk of malfunctioning or worsening the condition of urban forest parks in the future, because of the little attention paid to the soil quality. The increasing anthropogenic pressure, combined with the threats from climate change needs a deeper knowledge of the structure and functioning of the urban ecosystem and an urgent new management approach, based on knowledge of soil condition. Better maintenance of the green spaces and the application of appropriate management practices that consider soil quality as an important factor for the urban ecosystem balance are possible solutions for this challenge. This is directly linked to the need to include new approaches in management and a legislative basis for urban areas and urban forestry, which consider specific measures for improving soil-related ecosystem services.

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Conflicts of interest

References

- Adhikari K, Hartemink A (2016) Linking soils to ecosystem services — A global review. Geoderma 262: 101-111. https://doi.org/10.1016/j.geoderma.2015.08.009
- Alloway BJ (1995) Heavy metals in Soils. Blackie, London https://doi.org/10.1007/978-94-011-1344-1
- Artamonov (1986) Plants and purity of the natural environment, Series "Man and the Environment". Nauka
- Ballabio C, Panagos P, Lugato E, Huang J, Orgiazzi A, Jones A, Fernandez-Ugalde O, Morelli P, Montanarella L (2018) Copper distribution in European topsoils: An assessment based on LUCAS soil survey. Science of The Total Environment 636: 282-298. https://doi.org/10.1016/j.scitotenv.2018.04.268
- Baveye PC, Gowdy J (2016) Soil “Ecosystem” Services and Natural Capital: Critical Appraisal of Research on Un-certain Ground. Front. Environ. Sci 4 (41). https://doi.org/10.3389/fenvs.2016.00041
- Berkovits AR, Hollweg KS, Nilon CH (2003) Understanding Urban Ecosystems: a new frontier in science and education. 3. Springer [ISBN 978-0-387-22615-6]
- Bertine KK, Goldberg E (1972) Fossil fuel combustion and the major sedimentary cycle. Science 173: 233-235. https://doi.org/10.1126/science.173.3993.233
- Bratanova-Doncheva S (1988) Study on the migration of heavy metals in the soil-plant subsystem in representative forest ecosystems in "Freedom Park". University of Forestry
- Bunemann EK, Bongiorno E, Bai Z, Rachel E, Creamer R, De Deyn D, Goede R, Fleskens L, Geissen V, Kuyper T, Madder P, Pulleman M, Sukkel W, Groenigen J, Brussaard L (2018) Soil quality - A critical review. Soil Biology and Biochemistry 120: 105-125. https://doi.org/10.1016/j.soilbio.2018.01.030
- Burkhard B (2018) Mapping ecosystem service supply, demand and budgets. Ecological Indicators 21: 17-29. https://doi.org/10.1016/j.ecolind.2011.06.019
- Chuljian H (1978) Chemical states of copper in soil and their toxicity to plants. Diss. Institute of soil science.

- Common International Classification of Ecosystem Services, v.5.1 (2018) https://cices.eu/. Accessed on: 2022-12-15.
- Craul PJ (1999) Urban Soils: Applications and Practices. John Wiley and Sons
- de Groot RS (1992) Functions of nature. In: Cambridge University Press, et al. (Ed.) Functions of nature, evaluation of nature in environmental planning, management and decision making. Wolters-Noordhoff
- Dimitrov S, Georgiev G, Georgieva M, Gluschkova M, Chepisheva V, Mirchev P, Zhiyanski M (2018) Integrated assessment of urban green infrastructure condition in Karlovo urban area by in-situ observations and remote sensing. One Ecosystem 3 https://doi.org/10.3897/oneeco.3.e21610
- Doichinova V (2006) Heavy metals in soils under urbanized oak ecosystems from the Sofia region. Diss. Institute of soil science.
- European Environment Agency (2021) EUNIS habitat classification. https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification-1. Accessed on: 2022-12-10.
- Food and agriculture organization of the United Nations (2014) World reference base for soil resources. https://www.fao.org/3/i3794en/I3794en.pdf
- Gencheva S (2006) Classification and some features of anthropogenic soils. Sofia. University of Forestry.
- Gimond M (2022) Intro to GIS and Spatial Analysis. Online URL: https://mgimond.github.io/Spatial/index.html
- Gomez-Baggethun E, Gren D, Barton J, Langemeyer T (2013) Urban ecosystem services. Urbanization, biodiversity and ecosystem services: challenges and opportunities. A global assessment. Springer175-251. URL: http://link.springer.com/book/10.1007%2F978-94-007-7088-1
- Greiner L, Keller A, Grêt-Regamey A, Papritz A (2017) Soil function assessment: review of methods for quantifying the contributions of soils to ecosystem services. Land Use Policy 69: 224-237. https://doi.org/10.1016/j.landusepol.2017.06.025
- Guvenc H, Alagha O, Tuncel G (2003) Investigation of Soil Multi-element Composition in Antalya, Turkey. Environment International (29)631-640. https://doi.org/10.1016/S0160-4120(03)00046-1
- Haase D, Larondelle N, Andersson E (2014) A Quantitative Review of Urban Ecosystem Service Assessments: Concepts, Models, and Implementation. AMBIO 43: 413-433. https://doi.org/10.1007/s13280-014-0504-0
- ICP Forest Level I (2020) http://icp-forests.net/
- Larson WE, Pierce FJ (1991) Conservation and enhancement of soil quality. Evaluation for sustainable land management in the developing world : proceedings of the International Workshop on Evaluation for Sustainable Land Management in the Developing World, Chiang Rai.175-203.
- Li Y, Rouland C, Benedetti M, Li F, Pando A, Lavelle P, Dai J (2009) Microbial biomass, enzyme and mineraliza-tion activity in relation to soil organic C, N and P turnover influenced by acid metal stress. Soil bology & Biochem-istry 41: 969-977. https://doi.org/10.1016/j.soilbio.2009.01.021
- Luo X, Yu S, Li X (2012) The mobility, bioavailability, and human bioaccessibility of trace metals in urban soils of Hong Kong. Applied Geochemistry 27 (5): 995-1004. https://doi.org/10.1016/j.apgeochem.2011.07.001

- Mankova N (1989) Influence of aggravated ecological conditions of the urban environment on tree vegetation. University of Forestry.142
- Ministry of Agriculture (2008) Regulation No 3 on the standards for permissible content of harmful substances in soils. URL: https://lex.bg/laws/ldoc/2135595432
- National concept for spatial development (2013) https://www.strategy.bg/StrategicDocuments/View.aspx?lang=bg-BG&Id=774. Accessed on: 2023-2-14.
- National Statistical Institute (2015) https://www.nsi.bg/nrnm/show2.php?sid=57422&ezik=bul&e=12814
- Nedkov S, Zhiyanski M, Dimitrov S, Borisova B, Popov A, Ihtimanski I, Yaneva R, Nikolov P, Bratanova-Doncheva S (2017) Mapping and assessment of urban ecosystem condition and services using integrated index of spatial structure. One Ecosystem 2 https://doi.org/10.3897/oneeco.2.e14499
- Nedkov S, Borisova B, Koulov B, Zhiyanski M, Bratanova-Doncheva S, Nikolova M, Kroumova J (2018) Towards integrated mapping and assessment of ecosystems and their services in Bulgaria: The Central Balkan case study. One Ecosystem 3 https://doi.org/10.3897/oneeco.3.e25428
- Nemec K, Raudsepp-Hearne C (2012) The use of geographic information systems to map and assess ecosystem services. Biodiversity and Conservation 22 https://doi.org/10.1007/s10531-012-0406-z
- Nriagu JQ (1989) A global assessment of natural source of atmospheric trace metals. Nature 338 (338): 47-49. https://doi.org/10.1038/338047a0
- Oke TR, Mills A, Voogt C, Voogt JA (2017) Urban Climates. Urban Climates 2 https://doi.org/10.1017/9781139016476
- O'Riordan R, Davies J, Stevens C, Quinton J, Boyko C (2021) The ecosystem services of urban soils: A review. Geoderma 395 https://doi.org/10.1016/j.geoderma.2021.115076
- Panico SC, Memoli V, F. E, Maisto G, De Marco A (2018) Plant cover and management practices as drivers of soil quality. Applied Soil Ecology 129: 34-42. https://doi.org/10.1016/j.apsoil.2018.05.001
- Parr JF, Papendick RI, Hornick SB, Meyer RE (1992) Soil quality: attributes and relationship to alternative and sustainable agriculture. American Journal of Alternative Agriculture 7: 5-11. https://doi.org/10.1017/S0889189300004367
- Pouyat RV (2020) Urban Soils. Forest and Rangeland Soils of the United States Under Changing Conditions. Springer https://doi.org/10.1007/978-3-030-45216-2_7
- Robinson P, Metternicht G (2006) Testing the performance of spatial interpolation techniques for mapping soil properties. Computers and Electronics in Agriculture 50 (2): 97-108. https://doi.org/10.1016/j.compag.2005.07.003
- Sintorini M, Widyatmoko H, Sinaga E, Aliyah N (2021) Effect of pH on metal mobility in the soil. IOP Conference Series: Earth and Environmental Science https://doi.org/10.1088/1755-1315/737/1/012071
- Sofiaplan, Sofia Municipality (2021) https://sofiaplan.bg/
- Todorov L, Kirilov K (2022) Land use change and monitoring of endangered wetlands using geospatial technologies: A case study of Boyana marsh. Journal of the Bulgarian Geographic Society (47)3-14. https://doi.org/10.3897/jbgs.e94102
- Tuncay T, Bayramin I, Atalay F, Unver I (2016) Assessment of Inverse Distance Weighting IDW Interpolation on Spatial Variability of Selected Soil Properties in the

Cukurova Plain. Journal of Agricultural Sciences 22 (3): 377-384. https://doi.org/10.1501/Tarimbil_0000001396
- Urban Atlas, Copernicus Land Monitoring Service (2018) https://land.copernicus.eu/local/urban-atlas/urban-atlas-2018. Accessed on: 2023-2-14.
- Weiss MH, Harrison LB, Isaacs RS (1994) Use of decision analysis in planning a management strategy for the stage N0 neck. Arch Otolaryngol Head Neck Surg 120 (7): 699-702. https://doi.org/10.1001/archotol.1994.01880310005001
- Yang L, Li Y, Peng K, Wu S (2014) Nutrients and Heavy Metals in Urban Soils under Different Green Space Types in Anji, China. Catena 115: 39-46. https://doi.org/10.1016/j.catena.2013.11.008
- Yay OD (1998) Changes in the chemical composition of atmospheric pollutants. Middle East Technical University
- Zhiyanski M, Doichinova V, Ivanov P, Sokolovska M (2011) Characteristics of soils from urbanized forest parks in Sofia region. Proceedings of the International Conference "100 Years of Soil Science in Bulgaria".
- Zhiyanski M, Nedkov S, Mondeshka M, Yarlovska N, Borisova B, Vassilev V, Bratanova-Doncheva S, Gocheva K, Chipev N (2017) Part B1. In: Chlorind Ltd. (Ed.) Methodology for assessment and mapping of urban ecosystems condition and their services in Bulgaria. Clorind [ISBN 978-619-7379-03-7].

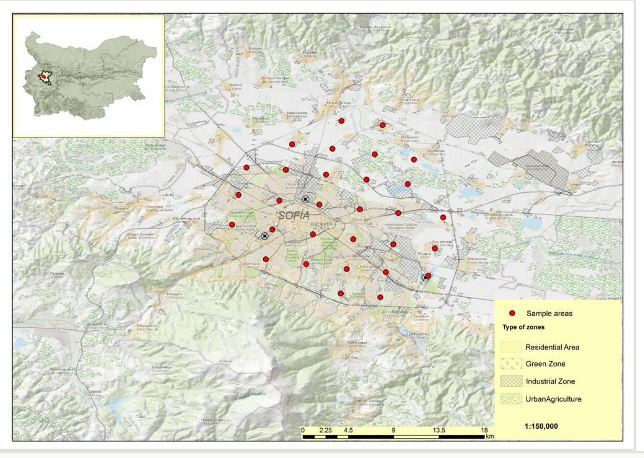

Figure 1.

Experimental plots in Sofia.

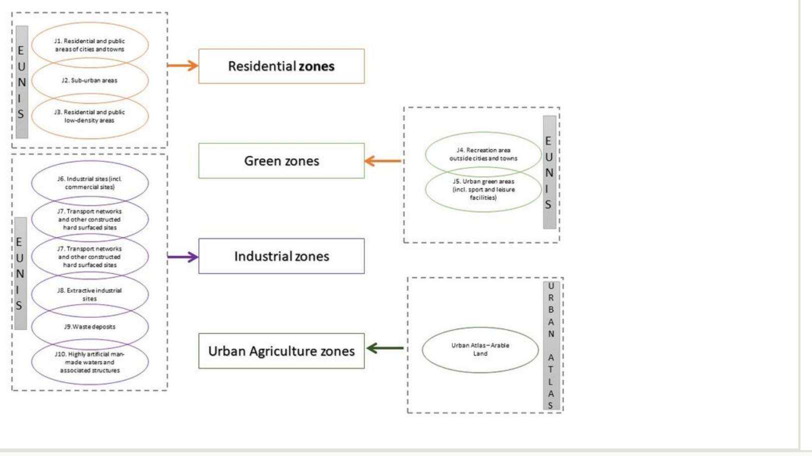

Figure 2.

Identification of functional zones in Sofia linked to the Methodology for assessment and mapping of urban ecosystems condition and their services in Bulgaria sub-types.

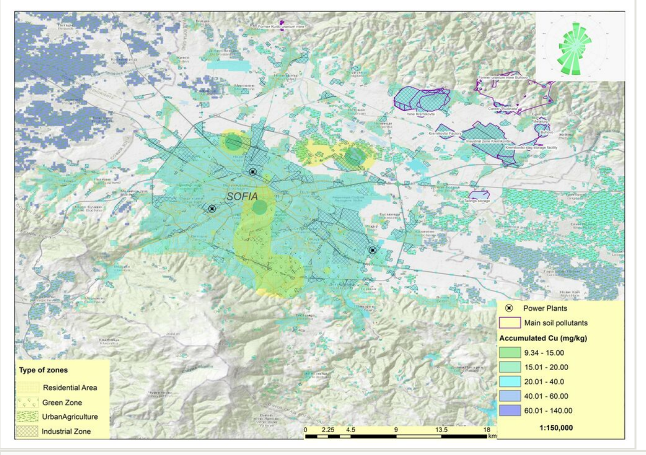

Figure 3.

Accumulation of Cu (mg/kg) in the soils from functional zones of Sofia. *Source of the wind rose – Meteoblue. Source of basemap – Google Maps.

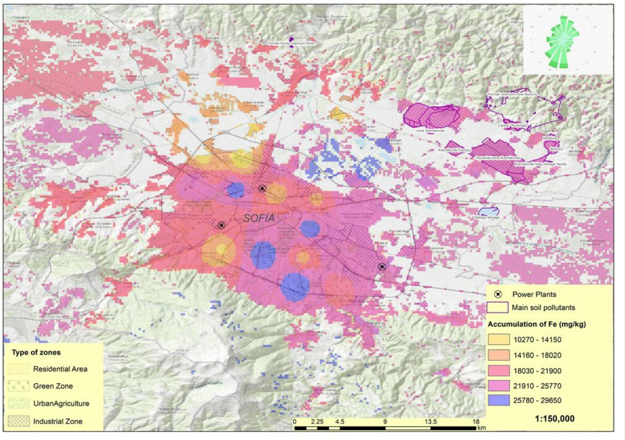

Figure 4.

Accumulation of Fe (mg/kg) in the soils in functional zones of Sofia. *Source of the wind rose – Meteoblue. Source of basemap – Google Maps.

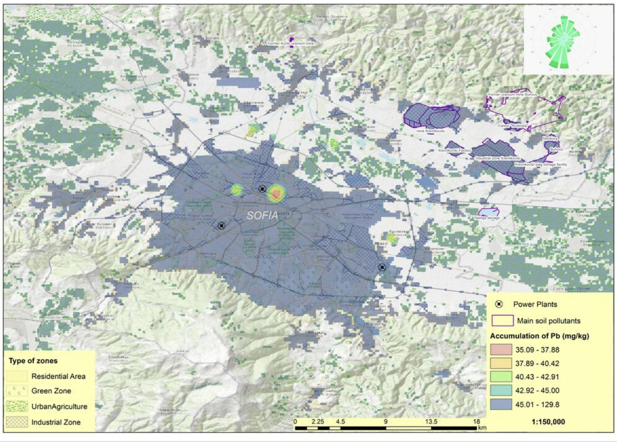

Figure 5.

Accumulation of Pb (mg/kg) in the soils of functional zones in Sofia. *Source of the wind rose – Meteoblue. Source of basemap – Google Maps.

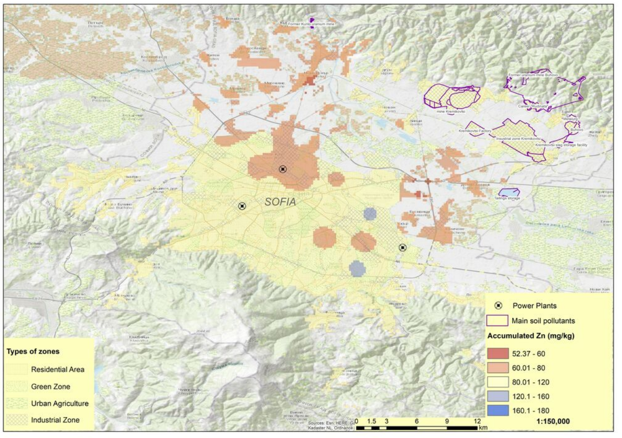

Figure 6.

Accumulation of Zn (mg/kg) in the soils of functional zones in Sofia. *Source of the wind rose – Meteoblue. Source of basemap – Google Maps.

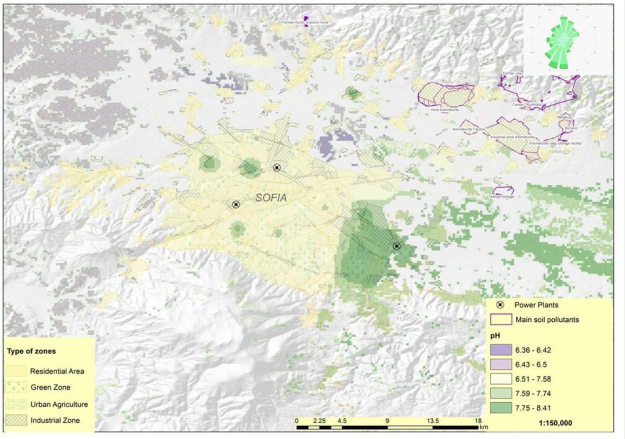

Figure 7.

Soil pH distributed by functional zones in Sofia. *Source of the wind rose – Meteoblue. Source of basemap – Google Maps.

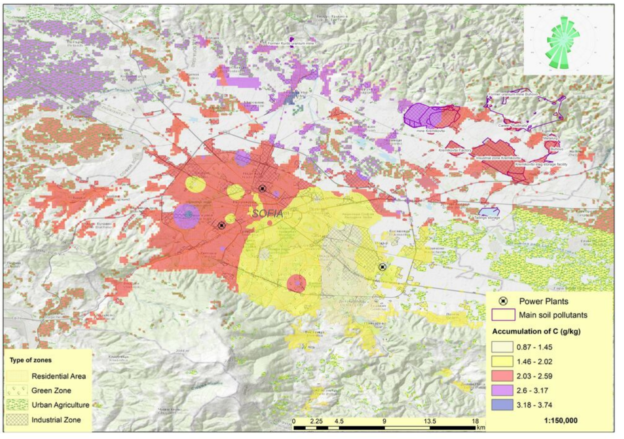

Figure 8.

Accumulation of C (g/kg) in the soils of functional zones in Sofia. *Source of the wind rose – Meteoblue. Source of basemap – Google Maps.

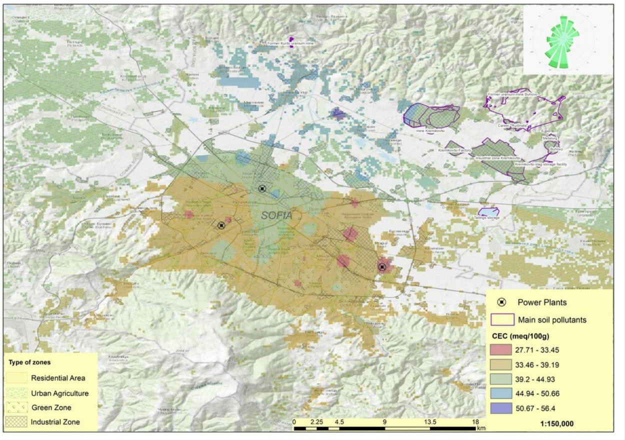

Figure 9.

CEC (meq/100g) in the soils in Sofia distributed by functional zones. *Source of the wind rose – Meteoblue. Source of basemap – Google Maps.

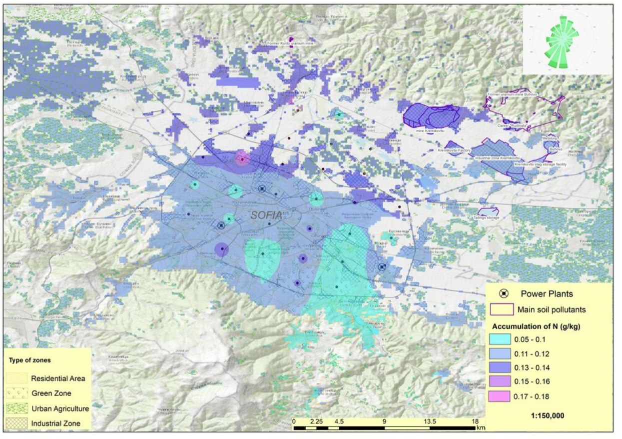

Figure 10.

Accumulation of N (g/kg) in the soils in Sofia distributed by functional zones. * Source of the wind rose – Meteoblue. Source of basemap – Google Maps.

Table 1.
Matrix for assessment of indicators.

Indicator	1 Very bad	2 Bad	3 Medium	4 Good	5 Very Good
Cu (mg/kg)	………	………	………	………	………
Zn (mg/kg)	………	………	………	………	………
Pb (mg/kg)	………	………	………	………	………
Fe (mg/kg)	………	………	………	………	………
C (g/kg)	………	………	………	………	………
N (g/kg)	………	………	………	………	………
CEC (meq/100g)	………	………	………	………	………
pH (H_2O)	………	………	………	………	………

Table 2.

Matrix for total assessment of the functional zones after Burkhard (2018).

Functional zone	C (g/kg)	N (g/kg)	pH (H_2O)	CEC (meq/100g)	Evaluation
Green zone	….	….	….	….	….
Industrial zone	….	….	….	….	….
Residential area	….	….	….	….	….
Urban Agriculture	….	….	….	….	….

Table 3.

Evaluation scores of heavy metals content in urban soils as indicators for anthropogenic pressure in the region of Sofia.

Indicator	1 Very bad	2 Bad	3 Medium	4 Good	5 Very Good
Cu (mg/kg)	60.01 - 140.00	40.01 - 60.00	20.01 - 40.00	15.01 - 20.00	9.34 - 15.00
Zn (mg/kg)	160.1 - 180	120.1 - 160	80.01 - 120	60.01 - 80	52.37 - 60
Pb (mg/kg)	45.01 - 129.8	42.92 - 45	40.43 - 42.91	37.89 - 40.42	35.09 - 37.88
Fe (mg/kg)	25780 - 29650	21910 - 25770	18030 - 21900	14160 - 18020	10270 - 14150

Table 4.
Evaluation scores of indicators for ecosystem service “soil quality”.

Indicator	1 Very bad	2 Bad	3 Medium	4 Good	5 Very Good
C (g/kg)	0.74 - 1.45	1.46 - 2.02	2.03 - 2.59	2.60 - 3.17	3.18 - 5.04
CEC (meq/100g)	26.40 - 32.74	32.75 - 39.08	39.09 - 45.42	45.43 - 51.76	51.77 - 58.1
pH (g/kg)	7.74 - 8.41	7.58 - 7.74	6.51 - 7.57	6.42 - 6.5	6.37- 6.41
N (g/kg)	0.08 - 0.1	0.11 - 0.12	0.13 - 0.14	0.15 - 0.16	0.17 - 0.18

Table 5.

Evaluation of the potential of urban functional zones to provide ecosystem service “soil quality”.

Ecosystem service Soil quality	C	CEC	pH	N	Total Evaluation	Mean
Green zone	2	3	3	2	10	2.5
Industrial zone	1	2	2	2	7	1.75
Residential area	2	2	2	2	8	2
Urban Agriculture	4	4	3	3	14	3.5

Table 6.

Evaluation of the Anthropogenic Pressure by functional zones.

Ecosystem service Urban Functional Zone	Cu	Zn	Pb	Fe	Total Evaluation	Mean
Green zone	4	3	2	3	12	3.08
Industrial zone	3	4	2	3	11	2.81
Residential area	3	4	1	3	11	2.77
Urban Agriculture	3	4	2	1	12	2.89