Evaluation and importance of soil functions in cities considering infiltration and climatic regulation

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Abstract

The functionality of natural extra-urban soils is now widely recognized in spatial planning after soil functions were introduced in the 1970s. However, the functionality of urban soils is often neglected in land-use planning despite the fact that biomass production, flood prevention, and ground water recharge are essential contributions of natural and anthropogenic urban soils for the livelihood of cities. Even less recognized but important are contributions of urban soils for sequestration of dust and carbon as well as their contribution to providing a comfortable urban climate by cooling and humidifying. Despite this, the significance of the functionality of soils during planning processes are often win-win situations for both, i.e. the quality of constructions and the quality of the urban environment. Furthermore, there is a significant potential to save money by considering the soil quality in planning and construction processes.

Key Words

Urban soils functions management evaluation climate

Introduction

Urban areas and the urban population grow rapidly since the 1930th. Globally, the proportion of people living in urban areas doubled since 1935, from approx. 25% to 50%. Thus, the functionality of soils in urban areas becomes more and more important for the quality of human life. Schematic soil evaluation systems have been mainly developed to assess a range of the functionality of natural soils. Relatively simple procedures have been developed to help in soil management. Otherwise, TUSEC (Technique for Soil Evaluation and Categorization for Natural and Anthropogenic Soils, Lehmann *et al.* 2008) was developed to assess both, natural and anthropogenic soils in the temperate regions. The evaluation of soils in urban areas should be the basis for the protection of high-quality soils from sealing and other degradations of soil functions. Also, urban soil evaluation is aimed to improve the quality of constructed soils.

The functionality of soils and its evaluation

Introduction of Soil functions

The term soil functions and, thus, the concept of multifunctionality of soils was introduced by Schlichting (1972). Schlichting adopted concepts established in forestry similar to the one documented by Endres (1905). The concept of soil functions was further developed by Brümer (1978) and initially adopted by the German federal state Baden-Wuerttemberg in the Soil Protection Act of the Federal State of Germany Baden-Württemberg (Umweltministerium von Baden-Württemberg 1991). Following a publication by Larson and Pierce (1994), the concept of soil functions became widespread globally. In 1998, the Federal republic of Germany introduced the Soil Protection Act of Germany (Bundesministerium der Justiz 1998). Recently, the European Union (European Commission 2006) discussed a soil protection law based on the protection of the following soil functions.

- biomass production, including agriculture and forestry
- storage, filter and transformation of nutrients, substances and water
- biodiversity pool, on the levels of habitats, species and genes
- physical and cultural environment for humans and human activities
- source for raw materials
- function as carbon pool
- archive of geological and archeological heritage

The set of soil functions differ when urban areas are the focus, specifically (Lehmann 2006):

Soil functions relevant for hazard protection in urban areas
- protection against rainstorm damages and flooding
- microbial decomposition of organic contaminants
- retention and immobilisation of inorganic contaminants

Soil functions relevant for production in urban areas

- renewable resources (clean water and air)
- plant products

Soil functions relevant for the environmental quality in urban areas

- dust capture
- carbon sequestration
- buffering of climate extremes, mainly through cooling by evaporation
- habitat for rare vegetation
- greenspace for recreational activities

Soil functions relevant for the cultural heritage of urban areas

- prehistoric and historic archives

Evaluation of the functionality of urban soils

Urban soils can be evaluated similar to natural soils if the specific properties of urban soils are considered. Most important are wider range of some parameters. Such parameters include, for example, the amount of organic matter in mineral soils, bulk density, CEC, EC and pH. In addition, features like high contents of coarse material and contamination must be included in evaluation procedures for urban soils. Table 1 provides an overview of common and rare expressions of parameters for anthropogenic urban soils.

Application of results from the evaluation of urban soils for spatial planning

For considering the functionality of soils in spatial planning, a simplification of the evaluation results (e.g., five-step scale as results of a schematic evaluation procedure for each function) and the integrated interpretation of the soil quality by experts is required. Such interpretations must place the evaluation results in the local context of ecology and planning. This is illustrated with examples in the following section, first focusing on soil water, and then on climate.

The first two examples deal with infiltration and transport of water in soils. In TUSEC the quantitative and qualitative aspect of the function "Soil as Component of the Water Cycle" is considered as well as the soil performance "Soil as Medium for Infiltration and Seepage". Soil performances are understood in TUSEC as facets of the ecological functionality of soils with direct economic value. Thus, soil performances allow to refrain from costly technical measures. Soil performances respected in TUSEC and considered particularly in urban areas are "soil as medium of infiltration and seepage".

Soil water

Two examples of recommendations basing of soil evaluation should illustrate how soil evaluation could contribute to spatial planning and constructing in points of water management:

At site I, the results of soil evaluation revealed that the projected reservoirs for the capture of precipitation will not be required. The soil capacity for absorbing precipitation in the area of the planned reservoirs even exceeds the storage volume of the reservoirs.

At site II, a building area was located on a hillside with a moderate slope gradient. There it turned out that the quantity of water which can infiltrate into the soils was calculated to be not sufficient. The reason for this wide-spread incorrect estimation is a low water permeability into the lower ground of the soils on the hillside. It was overlooked that the soil layers near the surface are often very permeable, also for lateral water flow. Such a composition of permeable and less permeable soil horizons is typical at many lanscapes with a relief. In fact, in such soils water seepage orientation is vertical only for a short distance before being diverting parallel to the hillside – so that water immediately drain down the slope to the next nearest water body.

Thus, it became obvious not only the evaluated soil, but also the surrounding soil and their relief positions as well as the proximity to a water body could be very important for the soil evaluation regarding water management. This means also that the evaluation of soils in relief areas needs a holistic approach. Only for flat areas it can be generalized that deep soils with silty texture and rich in organic matter are evaluated best.

Table 1. Common and rare properties of anthropogenic urban soils.

Characteristic	... Common in Anthropogenic Urban Soils	... Rare in Anthropogenic Urban Soils
Artefacts/ Fragments *(e.g., bricks, pottery, glass, crushed stone, industrial waste, garbage, mine spoil, mineral oil.)*	**At large portions** - in soils containing construction residues and other large artefacts *causing high water permeability* - in soils with surface or underground sealing	**None** - in soils developed from sludges and ashes - in soil from translocated natural soil material
pH	**Alkaline** - in soils containing carbonates from construction residues like plaster or concrete	**Acidic** - in soils containing sulphur from coal sulphuric acid
(Technical) Organic Carbon and Nutrients	**High** - in soils affected by accumulation of organic waste, dust and combustion residues - in soils formerly used for horticulture - in soils with subsoils containing former topsoil material	**Low in Organic Carbon** - in soils with regularly swept topsoil to keep it free from vegetation - in infertile soils **Low in nutrients** - in soils from parent material poor in nutrients
Contaminants	**High** - in soils containing combustion residues and other residues from industrial production processes	**Low** - in soils affected only by inputs of contaminants via dust deposition and rain
Bulk Density	**High** **- in the topsoil**: soils affected by mechanical forces on the surface **- in the subsoil**: soils affected by compaction through construction activities with big machinery used for excavation	**Low** - in soils affected by mechanically loosening - in soils high in organic matter - in soils containing high proportions of ashes
Soil Temperature	**High** - in city areas with increased air temperature (crucial for permafrost regions) - in soil affected by warm liquids or gases, or in neighborhood of warmed up technical cavities	**Low** - in soils affected by technical (induced) cooling and by cold water - in wet soils
Soil Moisture	**Low** - in soils affected by drainage, mostly for construction purposes	**High** - in soils affected by irrigation, by leakages, by drainage from sealed surfaces and by other fluxes of water
Age	**Young** - soils affected by frequent relocations due to construction activities	**Old** - soils situated in long time undisturbed niches in dow-town areas
Development	**Strong ex-situ** - soils built from relocated soil material from strongly developed soils, which was often deposited in layers during multiple constructions activities over longer times periods	**Diverse strong in-situ** - soils free of relocated strongly developed soil material (numerous soils from ≥ 50 years old show quite strong development, especially if they contain material of amorphic structure and material with large reactive surfaces, such as dust and ash)

Climate

Citizens suffer frequently during summer from high nighttime temperatures. Evaporation from the soil surface together with the evapotranspiration form soil grown vegetation provides a cooling effect and results in humidification of the air. Both effects make the urban climate comfortable for human health. However, the cooling effect of soils is rarely quantified. TUSEC undertakes a simple approach from rather restricted validity to quantify the cooling effect of soils expressed in $MJ*h^{-1}*m^{-2}$. The calculations are based on a modified method (from Renger and Wessolek 1996) to estimate site-specific averages for annual evaporation in Central Europe. For Germany, the cooling effect was calculated and tabulated for 70 climatically different sites and 8 classes of available field capacities. The site "Echterdingen" in Southwest Germany (mean temperature: 9.6°C, annual rainfall: 746 mm), near the airport Stuttgart with a Luvisol from Loess served as an example. The calculations for the cooling effect resulted in an available field capacity of approx. 230 l per square meter surface and 1.2 m depth for the Luvisol. The ground water table, however, is 10 m below the surface and therefore too deep to contribute to the amount of evaporated water. According to the input data (available field capacity, mean temperature and yearly rainfall) a cooling capacity of 1500 $MJ*h^{-1}*m^{-2}$ or 420 $kW*h^{-1}*m^{-2}$ was calculated for the soil volume of the Luvisol measuring 1∗1∗1.2 m. This cooling effect is equal to the cooling capacity of an air conditioner used in middle sized rooms of approx. 20 m^2. Such an air conditioner consumes 1120 kWh annually whereas the Luvisol consumes no electrical energy.

As long as the available field capacity determines the climatic evaluation of soils (beneath climatic parameters), the less compacted deep soils from silty and loamy texture rich in organic matter have to be protected with high priority. Also, the proximity of a soil to sealed areas and built-up areas increases the importance of the soil as irrigation does for enhanced evaporation.

Conclusion

The poor recognition of ecological functions of natural and anthropogenic urban soils by decision makers and spatial planners is clearly contradictory to their significance for environmental quality and hazard protection in cities. Also, the large potential of urban soils in terms of saving money based on the rational use of their functionality is in sharp contrast to the often inadequate use of soils and soil material for construction activities. This is obvious according to soil evaluation showing the high functionality especially of widespread urban soils with a high amount of organic matter. Therefore, the ecological functionality of urban soils has to be evaluated in the future with suitable methods and the evaluation results must be considered during spatial planning and construction activities

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