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Perspective Essay

# Towards an operational methodology to optimize ecosystem services provided by urban soils

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ABSTRACT

Urban soils need to be taken into account by city managers to tackle the major urban environmental issues. As other soils in forest or agricultural environments, urban soils provide a wide range of ecosystem services. However, their contribution remains poorly assessed up to now, and as a result there is a strong lack of consideration by urban planning of the services they provide. Indeed, urban soils are mostly seen as a land surface (land area, two-dimensional system) and if they are characterized, it is almost exclusively for their potential contamination and their geotechnical properties. So, policy makers and planning operators rarely consider soils as a living resource, capable to fulfill essential functions. From the conclusions of previous studies, a selection of ecosystem services provided by soil and adapted to the specificity of urban context is proposed. This paper also aims at proposing the concept of the DESTISOL decision support system for urban planning projects upstream of the planning decisions, illustrated by an application example. It is based on an integrative approach linking *soil quality indicators* (*e.g.* physico-chemical and biological characteristics, fertility, pollution), *soil functions* and *soil ecosystem services*. The method leads to the semi-quantitative assessment of the level of ecosystem services that are either provided by urban soils or required to fit with the urban design.

## 1. Introduction

Urban soils are an insufficiently recognized resource for the conception and construction of sustainable cities. Urban areas, in addition to global environmental issues, concentrate major local environmental concerns such as food-sufficiency, flood mitigation and urban heat island (Craul, 1992; Jenerette, Harlan, Stefanov, & Martin, 2011). To tackle those issues, every land surface – including cities – should be considered as a potential supplier of ecosystem services (Gómez-Baggethun & Barton, 2013). Ecosystem services are defined as the benefits human populations obtain, directly or indirectly, from the ecosystem (*e.g.* climate regulation, food production, energy supply) (Costanza et al., 1997; MEA, 2005). However, because of their high level of anthropization, urban soils are complex ecosystems that are poorly studied for their contribution to ecosystem services. So far, studies dealing with ecosystem services have focused mainly on natural (forest and aquatic habitat) or moderately anthropized (agricultural) environments (InVEST, 2015; UFORE, 2009). Indeed, the transposition of the concept of ecosystem services to urban environments is recent (Bolund & Hunhammar, 1999; TEEB, 2011) and mainly sectored. The research conducted so far refers to specific aspects, such as carbon storage in cities and global climate regulation (Davies, Edmondson, Heinemeyer, Leake, & Gaston, 2011; Herrmann, Shuster, & Garmestani, 2017; Jim & Chen, 2009; Lorenz & Lal, 2009; Pouyat, Groffman, Yesilonis, & Hernandez, 2002; Pouyat, Yesiloni, & Golubiewski, 2009; Pouyat, Yesilonis, & Nowak, 2006; Schmitt-Harsh, Mincey, Patterson, Fischer, & Evans, 2013), regulation of the urban heat island (Cameron et al., 2012; Jenerette et al., 2011; Lehmann, Mathey, Rossler, Brauer, & Goldberg, 2014; Norman et al., 2012), and green infrastructures (Cameron et al., 2012; Clergeau, 2012; Jim, 1998; Oberndorfer et al., 2007; Rhea, Shuster, Shaffer, & Losco, 2014).

Such a lack of knowledge leads to less consideration of urban soils by city managers and urban planners. Urban planning is defined as a technical and political process dealing with the organization of land

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use, the design of the urban environment, the welfare of people and the protection of the natural environment (Taylor, 2007). In urban planning, urban soils are mainly considered two-dimensionally by urban planners, as a surface area characterized by its land uses, where buildings and infrastructures can be built. The volume of urban soils is characterized only for geotechnical properties or contamination levels. Urban planners do not consider urban soils as a potential living, fertile and tri-dimensional compartment of the urban ecosystem able to perform highly diversified functions and provide ecosystem services (Morel, Chenu, & Lorenz, 2014).

Soil functions are the product of their physical, chemical and biological characteristics (Natural Capital), and the processes they generate (Schindelbeck et al., 2008). Soil quality refers to the capacity of a soil to function within a given ecosystem and land use boundaries, to sustain productivity, maintain environmental quality and promote plant and animal health (Doran & Parkin, 1994; Vrščaj, Poggio, & Marsan, 2008). Taking into account urban soil quality into urban planning strategy would contribute to the mitigation of the major environmental issues and to the development of sustainable and resilient cities by optimizing ecosystem services. This goal requires a reconsideration of the management of urban areas, and the development of a full chain of knowledge, techniques and tools. Hence, cooperation should be promoted between soil scientists and urban planners. As a result, to develop sustainable management of urban areas, it is of utmost importance to build decision support systems (DSS) that take into account ecosystem services provided by soils. The concept of ecosystem service, with its advantage of being understood and shared by the various actors of urban development (*e.g.* policy makers, operators, urban planners), shall be the cornerstone of such a DSS.

Therefore, this paper was aimed at i) emphasizing the original features of soils in the urban ecosystem, ii) proposing, from the most recent knowledge, a contextualized list of ecosystem services provided by urban soils, iii) analyzing existing urban soil quality assessment tools to formulate propositions for an operational approach, and (iv) proposing and giving an example of application of a new type of DSS based on an integrative approach, linking *soil indicators*, *soil functions* and *soil ecosystem services*, in order to improve urban planning.

## 2. Urban soils as by-products of human activities and key components of urban ecosystems

"*Urban soil constitutes the archaeological deposit between the present surface and the natural roof levels and is located in the historic city center*" (Fondrillon, 2007). Such an archaeological definition describes the urban soil only by its historical formation and its location in the territory. It should be completed by the World Reference Base for Soil Resources (WRB), which defines the soil as "*any material within two meters of the Earth's surface that is in contact with the atmosphere, excluding living organisms, areas with continuous ice not covered by other material, and water bodies deeper than two meters*" (IUSS Working Group WRB, 2015). In the present paper, we used the term urban soils to refer to "*soils that are under strong human influence in the urban and suburban landscape*" (de Kimpe & Morel, 2000), whether in presence or absence of vegetation. Also, "urban soil" may stand for all soils under human influence that can be found not only in urban areas, but also in a wider range of locations (*e.g.* soils from an industrial brownfield are considered as urban soils in this paper). In this case, urban soil is synonym of SUITMA (Soils of Urban, Industrial, Traffic, Mining and Military Areas) (Morel et al., 2014).

At the urban area scale, human influence leads to a great variety of soils on a limited surface area (compared to natural environments) and to a lack of spatial logic (Effland & Pouyat, 1997; Morel & Schwartz, 1999). It should be noted that deeply degraded soils, strongly transformed soils and pseudo-natural soils showing only little changes, may coexist in urban areas (Morel et al., 2014). This high variability could be explained by the fact that urban soils are characterized by a wide range of various activities over time (Norra & Stuben, 2003) and by a very frequent change of use. More precisely, urban soils may result in the combination, in various proportions, of exogenous materials – either anthropogenic (so called technic materials), geologic or soil materials – and of native soils. At the pedon scale, they present a strong vertical and horizontal spatial heterogeneity of their physical, chemical and biological properties (Béchet et al., 2009; Craul, 1992; Morel, Schwartz, & Florentin, 2005; Schwartz, 2001). Urban soils are associated with a large range of features, among them coarse texture, high bulk density, alkaline pH are specific to urban soils (Burghardt, Morel, & Zhang, 2015; Joimel et al., 2016; Kida & Kawahigashi, 2015; Leguédois et al., 2016; Pouyat et al., 2007; Shaw, 2015). Furthermore, the incorporation of artefacts as well as residues from human activities (*e.g.* traffic, industry) may cause contamination (Béchet et al., 2009; Craul, 1992; El Khalil et al., 2013; Joimel et al., 2016) in the coarse fraction and fine earth (El Khalil et al., 2008). As a consequence, the physical and chemical fertility of urban soils is often low, even if some of them are designed to provide a suitable medium for plant growth and biomass production (*e.g.* in green areas, gardens, green roofs, constructed soils) (Joimel et al., 2016; Morel & Schwartz, 1999; Rokia et al., 2014; Séré et al., 2008). Despite all their original characteristics, soils in urban ecosystems are capable of providing ecosystem services in a similar way as agricultural or forest soils.

## 3. Ecosystem services provided by urban soils to face major urban environmental issues

Urban areas are confronted by specific, major environmental issues (*e.g.* food dependency, local climate), as they concentrate population, activities and infrastructures. Ecosystem services provided by urban environments are rarely linked with soils. However, urban soils and their associated ecosystem services are crucial for the management of most of those environmental problems. For natural environments, the functional capacity of soils is used in an interdisciplinary framework to assess ecosystem services and "*to focus on exploring soil functional diversity of soil biota and the spatial aspects of soil properties to lower level ecosystem services*" (*e.g.* Adhikari & Hartemink, 2015; Dominati, Patterson, & Mackay, 2010; Morel and Heinrich, 2008). Despite an increasing number of papers dealing with "ecosystem services" and "urban soils" (7 papers in 2005 and 50 in 2015), the ratio of the number of papers citing "ecosystem services" + "urban" + "soil" on the number of papers mentioning only "ecosystem services" has remained stable. Recently, a semi-quantitative evaluation of four categories of SUITMAs: sealed soils, landfill soils, pseudo-natural vegetated soils and constructed vegetated soils was proposed (Morel et al., 2014). In urban areas, whatever the degree of anthropization of soils, they all can provide services in order to sustain and fulfill human life. As an example, vegetated pseudo-natural soils ensure better habitats for biodiversity than dumping sites, or in extreme cases, than sealed soils. In the same extent, sealed soils ensure the transportation of goods, energy, and human beings, unlike vegetated constructed soils. As a result, compromises have to be made, as a given soil cannot provide the whole range of services.

Following the propositions of many authors (*e.g.* Escobedo, Kroeger, & Wagner, 2011) and adapting the existing lists (Costanza et al., 1997; de Groot, Wilson, & Boumans, 2002; MEA, 2003) to the urban context, we have established an integrated list of ecosystem services provided by soils in the urban environment (Table 1). Considering the international agreement on the status of "supporting services" (Dominati, 2013), and the idea that the quantification of ecosystem services needs to focus only on benefits directly useful to humans, it appears more relevant in the urban context to express this concept as a "soil's capital" (Fischer, Kerry Turner, & Morling, 2009). Indeed, as previously mentioned, urban soils are singular in the association of natural and technical components, as some of them were implemented on purpose to enhance their functions (*e.g.* pipes, underground structure, bitumen). So,