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URBAN SOILS AND SEDIMENTS

Preface

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Cities have recently become the home for more than half of the world's population and are expected to contain 66 % of humankind by 2050. As human constructed environments, cities disrupt natural cycles and the patterns of temporal and spatial distribution of environmental and ecological processes (UN 2014). Urbanization causes breaks in connectivity of ecological, hydrological, nutrient, and energy cycles and fluxes that can lead to enhanced exposure to disruptive events (Escadafal et al. 2015; Ndah et al. 2015; Laudicina et al. 2015).

To make cities more resilient and sustainable from an ecological, hydrological, and energy point of view, new strategies are needed, especially in the light of fast-growing cities due to high population growth, reduced fossil fuel availability, and climate change. Urgent measures are needed in developing countries to make cities greener, more resilient, and self-sustained. Examples of this include the use of green spaces (Udeigwe et al. 2015) and urban agriculture (Beniston et al. 2015). The goal of these different re-greening approaches is to reduce the impacts of the built environment, allowing the maintenance of high levels of biotic and abiotic connectivity (Parsons et al. 2015), improving primary productivity inside cities, and therefore increasing the amount of and options for managing bioenergy, chemical fluxes, and trade of food assets produced within.

Re-greening strategies contribute to the implementation of a low carbon/circular economy; however, this cannot be achieved without risks because the re-greening strategies rely on soil and urban soils that are or have been polluted by urban or industrial activities. Therefore, soils are fundamental in this context. They are the most important media where harmful and persistent pollutants are accumulated and where the degradation of these compounds takes place (Decock et al. 2015; Keesstra et al. 2015a; Smith et al. 2015). The study of soils is essential when developing strategies for sustainable cities. Soil science in combination with hydrology, ecology, and agronomy can produce holistic strategies for mitigating the risks in urban environments (Keesstra et al. 2015b).

The soil system is heterogeneous, varied, and spatially and temporally dynamic. This makes it difficult to monitor and develop strategies to increase its resilience. Reclamation of polluted soils, either resulting from point or diffuse pollution, is a complex task and yet of paramount importance to increase ecosystem resilience, maintain the environmental services they provide, and improve overall community health (Brevik and Sauer 2015; Zornoza et al. 2015).

Among the environmental ecosystem services provided by urban soils, we can include climate control and regulation of carbon and nitrogen emissions, control of pests and diseases, support of primary production through organic matter and nutrient cycling, and decontamination of the environment and food (Brevik et al. 2015). In fact, soils are a valuable

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natural resource with filtering, buffering, and energy-transforming properties; they provide a reserve of genes and water as green water or groundwater, which is a source of plant nutrition, and a basis of human activities (Brevik and Arnold 2015; Gelaw et al. 2015; Hu et al. 2015; Ono et al. 2015). Soils are typically the decay-processing "factory", transforming dead organic matter into mineral forms usable by vegetation and other life forms. For these reasons, it is of utmost relevance to their maintenance and sustainable use.

In urban areas, the capacity of soils to provide ecosystem services is highly reduced by the impact of human activities (Morel et al. 2015). Urban soils are intensively used and affected by human activities. They are often young soils in the early stage of development and composed of technogenic materials (Lehmann 2006; Lehmann and Stahr 2007; Rossiter 2007). The World Reference Base for Soil Resources (WRB) (WRB 2006) classifies urban soils as "Technosols". They are different from other soils due to the presence of artifacts of urban or industrial origin (e.g., ceramic, glass, bricks, industrial waste, garbage, crushed or dressed stone, and oil products) and may be covered by technic hard rock (e.g., road pavement and cement building areas). Differentiation of urban soils depends on the presence of technogenic materials, land use form, human impact intensity, and site age (Greinert 2015).

Soils are impacted by urbanization in different ways relevant to the ecosystem functions and to environmental services they provide and the wellbeing of human societies: (i) they increase the impervious area, changing the generation threshold and magnitude of hydrological processes at different scales, with impact on flash flood risk and it's mitigation approaches; (ii) they influence the source, transport, and fate of pollutants in urban areas, where interaction with vegetation plays an important role in the transmission of pollutants from the atmosphere to the soil; (iii) their role as providers of ecosystem services to the urban environment that can be managed to reduce risk and improve resources governance; and (iv) as supporters of urban agriculture, soils combine the promise of increasing sustainability and lowering carbon consumption with threats to human and ecosystem health as a result of higher pollutant concentrations and increased frequency and magnitude of catastrophic unforeseen events.

Urban soils often have high levels of heavy metals and polycyclic aromatic hydrocarbons (PAH's). The high concentrations of these elements are one of the main causes of soil degradation. This is a serious problem in cities located in emerging economies such as China (Wei and Yang 2010; Wang et al. 2013), India (Chabukdhara and Nema 2013; Subramanian et al. 2015), Brazil (Ribeiro et al. 2012; Rodrigo et al. 2014; Garcia et al. 2015), Mexico (Mireles et al. 2012; Garcia-Flores et al. 2016), in old industrial areas of Europe (Cachada et al. 2012; Rodrigues et al. 2013), Japan (Yang et al. 2002), and the United States (Laidlaw et al. 2012; Burt et al. 2014). Recently, pharmaceutical components (e.g., antibiotics) started to be a concern in urban soils because of their high content as a consequence of wastewater irrigation of green areas (Wang et al. 2014; Gao et al. 2015). All the substances mentioned have a strong negative impact on soil functions and human health (Brevik 2009; Luo et al. 2012; Yuan et al. 2014a, b; Garcia et al. 2015). Toxic metals, PAH's, and pharmaceutical components can affect human health through direct ingestion, oral intake, dermal contact, inhalation, and diet through the soil-food chain (Thiele-Bruhn 2003; Liu et al. 2013; Malchi et al. 2014; Wang et al. 2015). High concentrations of heavy metals and PAHs in soils, vegetables, and fruits are known to increase the risk of cancer (Turkdogan et al. 2002; Hough et al. 2004; Wang et al. 2011).

Soils in urban and industrial areas are degraded and subjected to strong disturbances such as artificial sealing by paved roads. Soil sealing has important impacts on ecological functions and decreases water infiltration, biodiversity, and the capacity of soil to act as a carbon sink (Scalenghe and Marsan 2009; Khaledian et al. 2016). Soil sealing has two major implications for overland flow dynamics: (i) the increased velocity and destructive impact of flash floods that may result in lost lives and high economic costs in the flooded areas (Barroca et al. 2015; Elga et al. 2015); and (ii) the increased amount of sediments and pollutants transported (Maniquiz-Redillas and Kim 2014; Li et al. 2015) and deposited in water bodies (Moreno-Gonzalez et al. 2013; Namour et al. 2015), contributing to habitat degradation and reduction of the quality of the services provided by these ecosystems, as we will describe further.

Soil degradation is common in urban parks, gardens, trails, and roads (Fig. 1a) as a result of the non-sustainable management practices carried out by municipal workers, such as the removal of litter from the soil surface (Fig. 1b). This contributes to increased sediment availability that is easily transported after rainfall and snow melt (Fig. 1c), leading to the formation of rills and gullies (Fig. 1d). Sediments in urban areas are divided into two types: (i) those deposited on road surfaces and transported by sub-aerial processes, and (ii) those transported and deposited in lakes, rivers, canals, and docks. Sediments deposited on roads, storm sewers, and gullies are only stored over the short term, while sediment storage in river channels depends on the texture. Fine-textured sediments (clays, silts, and fine sands) can remain from days to months, whereas coarser sediments (e.g., coarse sands and gravels) can be stored from years to decades. The same time of sediment storage is observed in canals, docks, and floodplains. Nevertheless, the presence of the sediments in these areas may not be permanent, as a consequence of floodplain bank erosion and the dredging of docks, canals, and channels (Taylor and Owens 2009).

The main sources of sediments for road-deposited sediments (RDS) are eroded soil, plant and leaf litter (natural

Fig. 1 Soil degradation and sediment accumulation in roads in Vilnius (Lithuania) **a** road trail, **b** municipal clean-up activities, **c** sediment accumulation, and **d** rill and gully formation

sources), atmospheric deposition of particles, road salt, building and construction debris, road paint material, brake-liner material, vehicle exhaust emissions, vehicle body wear, and vehicle tire. In these areas, the single most important source of sediments is from soils (e.g., urban parks and gardens) rich in minerogenic organic material and building materials that are rich in concrete, cement, and quartz sand. The source of sediments in rivers is larger than the RDS since they also receive input from non-urban areas (outside the city, such as agricultural areas and forests), mass movements, soil erosion, and channel bank material. In canals, the source of sediments is mainly local, consisting of sewage, industrial, and material transported from roads. Nevertheless, there are exceptions, such as when canal and dock areas receive a large input of water from rivers, which transport a large amount of sediments (e.g., Delft Canals, The Netherlands). Sediment transport in urban areas is very complex, and the pathways of sediment transport from their source to the water bodies where they are eventually deposited are very poorly understood. These sediments can take various routes depending on natural and man-made conditions (Taylor and Owens 2009; Garcia-Martinez and Poleto 2014).

Urban sediments are composed of different types of material including biogenic, organic and inorganic materials, and mineral compounds (Garcia-Martinez and Poleto 2014). They have a high content of pollutants as a consequence of human activities (Selbig et al. 2013). One of the main sources of RDS is eroded soil and anthropogenic material; thus, it is expected that they are highly contaminated with metals (Zhu et al. 2008; Krcmova et al. 2009; Sutherland et al. 2012; Yuen et al. 2012; Zhao and Li 2013) and PAH's (Liu et al. 2016; Trujillo-González et al. 2016). Contamined road-deposited sediments have a high spatial variability, depending on the sources of contamination such as traffic circulation, industrial areas, and the street environment. Temporal variability is dependent upon weather patterns. At the monthly level, some variability can be identified at the local scale, which is attributed to seasonal weather patterns (Taylor and Owens 2009). For example, the high transport of metals in runoff occurs in the period immediately after dry periods, because of the high accumulation of sediments (Zhang et al. 2015b).

Previous works observed that the concentration and availability of metals (Sutherland et al. 2012; Zhao and Li 2013) and PAHs (Selbig et al. 2013; Zhang et al., 2015a) increased with decreasing particle size. The high concentration of metals in smaller particles is attributed to the increased surface area with decreasing sediment size, providing a greater surface area for metal sorption to organic matter or clay minerals. The mobility of nutrients in RDS is relatively low, because the majority of the metals are in their reducible fraction. However, their availability can increase after deposition in water bodies as a result of pH changes (Sutherland et al. 2000; Taylor and Owens 2009). Other elements of anthropogenic origin are also found in RDS such as perfluoralkyl acids (PFAAs) (Xiao et al. 2012), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs) (Jartun et al. 2008), pesticides, herbicides, fertilizers (Loganathan et al. 2013), and platinum group-elements (Sutherland et al. 2007).

As a consequence of the high sediment availability in urban areas and presence of anthropogenic pollutants in urban soils and RDS, it is expected that urban runoff contains a high quantity of total suspended solids and pollutants (Li et al. 2012; McCarthy et al. 2012; Gilbreth and McKee 2015; Weston et al. 2015) that can contaminate freshwater environments (e.g., rivers, lakes, estuaries) (Xiao et al. 2013; Yuan et al. 2014a, b; Martinez-Santos et al. 2015). In addition to the sediments and pollutants transported in runoff, wastewater discharges also contribute to aquatic environment pollution (Rodriguez-Mozaz et al. 2015).

The accumulation of pollutants in water bodies is a very important question in urban areas around the world because of the bioaccumulation of these products in the flora and fauna and the toxicity that they induce in the surface waters of these aquatic environments (Klosterhaus et al. 2013; Tong et al. 2013; Valdes et al. 2014), with important implications for the quality of the ecosystem services provided by these areas and on the risk to human health (Robinson et al. 2016). It has been reported that high contents of pollutants of anthropogenic origin are deposited in ground and surface water bodies near large urban areas in the North and South America (Ensminger et al. 2013; Felix-Canedo et al. 2013; Alves et al. 2014), Europe (Lopez-Serna et al. 2013; Kanzari et al. 2014; Deycard et al. 2014), Asia (Liu and Wong 2013; Islam et al. 2015), Africa (Nyenje et al. 2013; Amdany et al. 2014) and Australia (Nguyen et al. 2014; Allinson et al. 2015). This is a phenomenon that needs global attention and cooperation to be solved.

Intense rainfall periods and drought spells are expected to be more frequent and intense as a consequence of climate change (Childers et al. 2015; Pereira et al. 2016). The increase in precipitation amount, intensity, and frequency in urban areas is expected to produce an increase in the peak and volume of storm runoff (Rawlins et al. 2015; Zahmatkesh et al. 2014), transporting a high quantity of sediments and pollutants to water bodies. To mitigate the impacts of climate change in urban areas, it is important to reduce soil surface sealing, limit urban sprawl, favor the development of green infrastructure, and favor policies that promote compact cities and green roof implementation (Pereira et al. 2014). Green roof development contributes to decreased greenhouse emissions, building energy consumption, urban heat island effect, and runoff (Berardi et al. 2014).

The objective of this special issue was to showcase the latest advances in the study of urban soils and sediments. The 12 papers present in this issue cover a number of important topics related to urban soils and sediments, such as soil formation (Burghardt and von Berhrab 2016), structure amelioration (Zimmermann et al. 2016), spatial and temporal water dynamics (Wiesner et al. 2016), human impact on urban park soils (Sarah et al. 2016; Zhao and Hazelton 2016), the application of spectroscopy to urban soil studies (Kopel et al. 2016), green roof soils (Jelinkova et al. 2016), urban streamflow regimes (Ferreira et al. 2016a), and the transport of sediments, heavy metals, and polychlorinated biphenyl in urban areas runoff (Dias-Ferreira et al. 2016; Ferreira et al. 2016b, c; Silveira et al. 2016). This volume presents the latest research and case studies from several urban areas located in Europe, America, Australia, and Asia, contributing to the knowledge of urban soil and sediment dynamics at the international level. We hope this volume will be useful for further works and the readers enjoy the papers published, as we enjoyed collecting them for this special issue.

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