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Degradation in Urban Areas

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Abstract

Over the few last decades, increasing population and expansion of urban areas has triggered faster land degradation. This manuscript reviews the most significant soil and water degradation processes in urban areas and their environmental impacts. Urban soils are partially sealed and subject to severe compaction, erosion and contamination from several sources (e.g. vehicular traffic and inappropriate waste disposal), which restrict their ability to provide ecosystem services. Water resources are also under great urban pressure, due to

Persistent pollutants such as heavy metals and polycyclic aromatic hydrocarbons have been found in urban environments. Long-term monitoring programs to quantify better the magnitude of degradation processes and their environmental impacts are still required. Runoff, erosion and pollutant sources as well as their transport within the landscape are highly variable, and the impact of distinct urban patterns on water, sediment and pollutant connectivity between the sources and water bodies remains a research challenge. Information regarding land degradation processes and their spatio-temporal dynamics within urban catchments will help to guide decision-makers and policy actors towards sustainable solutions to achieve urban sustainability and the good ecological status of aquatic ecosystems.

Keywords: urbanization, land degradation, soil, water resources, contaminants

1. Introduction

World population has increased exponentially over the last few decades and is expected to reach 10 billion by 2056 [1]. Currently 54.9% of total population lives in urban areas [1], but by 2050 the urban fraction will have reached 66% of world population and 82% of European population [2]. Since 1950s the urban surface area in Europe has expanded by 78%, while the urban population has grown by just 33% [3]; this is due to much of the expansion being in peri-urban areas (transition zones between urban and rural areas) where urban areas are expanding at four times this rate [6]. In 2012, the land taken for urban development in 39 countries of Europe exceeded 1000 km^2 per year, which is an area three times the size of Malta [4].

Land is a complex resource composed primarily of soil, water and biodiversity [4]. It is also a finite resource providing important ecosystem goods and services to society [7]. Land consumption through urbanization and peri-urbanization has adverse environmental effects, such as (i) climatic change, primarily via the urban heat island [8]; (ii) loss of biodiversity due to vegetation removal and landscape fragmentation, which in turn increase endangered species and the spread of invasive species [4]; and (iii) soil, water and air contamination [9,10], with negative impacts on human health.

Soil degradation in urban areas, including sealing, compaction and erosion, has several detrimental impacts on urban welfare and sustainability. For example, urbanization of steep slopes has been responsible for many landslides, some of them causing human fatalities, as well as economic and property damage [11]. Soil degradation also impairs ecosystem services provision [7], enhances the vulnerability of urban communities to natural hazards and climate change impacts, with consequences for water, energy and food availability [11]. For example, inadequate urban planning and management enhances flood hazard [12]. Floods are among the most common, dangerous and costly of all natural disasters, affecting the livelihoods of millions every year [13]. In the European Union, annual estimated costs of floods averaged €4.9 billion between 2000 and 2012, but may increase to €23.5 billion

It is important that processes of soil and water degradation associated with urbanization are understood and considered when formulating planning and adaptation strategies to achieve more sustainable urban development. This manuscript reviews recent literature on soil and water degradation processes in urban and peri-urban areas, highlighting research gaps and proposing ways forward to mitigate land degradation due to urbanization.

2. Soil degradation

Soils are an important part of the urban ecosystem, but they are highly susceptible to sealing, compaction, erosion and contamination (Figure 1), which are recognized as some of the main threats to European soils [16].

2.1 Physical degradation

Sealing is the covering of soil by artificial materials of limited permeability (e.g. asphalt and concrete). Soil sealing is effectively irreversible and affects ecosystem services, such as water infiltration and groundwater recharge [17], carbon sequestration [18], habitat fragmentation and loss of soil biodiversity [16], which in turn inhibits or slows down nutrient cycles [19]. In EU27, up to 35% of biodiversity is expected to be lost from 2000 to 2030 due to soil sealing [20]. Sealing also affects the scale of heat island effects [8], since highly sealed areas can be up to 20°C hotter than green shaded surfaces [21].

In the EU, the area of artificial surfaces increased from 4.1% in 1990 to 4.4% in 2006 [22]. Soil sealing is not regulated at the European level, but guidelines to reduce the percentage

Soil compaction is a form of physical degradation resulting from human and animal trampling (including in gardens) and vehicular traffic, particularly of heavy machinery during construction work. It involves the degradation of soil biological activity and soil productivity of food and biomass, and leads to reductions in water infiltration and the storage capacity of soils, and resultant increases in erosion risk on sloping ground [16]. Soil compaction is linked to higher bulk density, reported to be 30% greater in urban than agriculture areas, and 60-90% higher than in forest soils [17].

In urban environments, soil erosion is prone to occur in areas of bare soil, in construction sites and along road edges [22,23], due to disturbed soil profiles and low organic matter content, which enhance soil susceptibility to erosion by rainsplash and overland flow during rainfall events [24]. Types of soil erosion by water include sheet erosion (also called slopewash), rill erosion and gully erosion. Gullies represent the most severe form of erosion, and although physical processes leading to gully initiation and evolution are similar in urban and rural areas, the development of urban gullies is closely related to construction activities, road development and inadequate planning of the urban drainage system [25].

Erosion depletes fertile topsoil, leading to land degradation and off-site problems such as siltation of surface water bodies. Furthermore, it is often linked to reduced environmental quality due to potential contamination from urban eroded soils.

Soil erosion is one of the greatest worldwide environmental concerns [26]. In the EU28, around 11.4% of territory is characterized by a moderate to high soil erosion rate (>5 Mg ha^{-1} per year) and 0.4% of land suffers from extreme erosion (>50 Mg ha^{-1} per year) [4].

sediment control measures as important aspects of catchment management [26].

2.2 Chemical degradation

Soil contamination is prone to occur in urban areas as a result of excessive amounts of contaminants released by industrial, domestic and commercial activities, transport and inadequate waste disposal, from both proximal (e.g. vehicle emissions and domestic heating) and more distal (e.g. atmospheric transport) sources [28]. Pollutants found in urban soils include heavy metals, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and phthalate esters/phthalic acid esters (PAEs) [8,29].

Soil contamination by heavy metals can arise from the use of wastewater for irrigation in parks, road traffic and the use of sewage sludge [30]. Sites close to traffic routes are typically enriched with heavy metals, directly related to the frequency of vehicles, as a result of tyre wear particles and weathered street surfaces [31]. Heavy metals have been subject to increasing attention because they persist in the environment [32]. Thus they may cause adverse ecological effects through their impact on activities of soil organisms, disruption of biogeochemical cycles and changes on foodweb functioning [16]. Heavy metals can come into contact with humans as suspended dust or by ingestion in soils of kindergarten [33], urban parks and lawns [34] and urban woodland soils [30], thus causing human health effects [33].

PAHs in urban soils result from long-term deposition of contaminated particulates [29]. They primarily originate from anthropogenic sources such as vehicular emissions, fossil fuel combustion and chemical manufacturing [29,35]. PAEs, in turn, have been attributed to atmospheric deposition [29]. PAHs and PAEs represent major groups of toxic pollutants that can be found in urban soils at potentially hazard levels.

Urban soils are considered to be regional sinks of chemical emissions [34], with higher background contents of pollutants, although not necessarily exceeding risk levels. The Directive 2010/75/EU [36] provides a list of human activities posing a risk of contaminant emissions. In 2011-12, the European Soil Data Centre identified 2.5 million contaminated sites by point pollution and estimated 11.7 million potentially contaminated sites across Europe [37]. Annual management of contaminated sites are estimated to cost around €6 billion [37].

3. Water resources degradation

3.1 Hydrological changes driven by urbanization

Urbanization modifies the rainfall paths of the natural water cycle, through (1) the replacement of vegetation by sealed surfaces, (2) changes in soil physical properties driven by urbanization, such as aggregate arrangement, pore space and soil hydraulic properties [38], and (3) the use of artificial drainage systems, which collect excess runoff from urban surfaces and convey it to stream channels.

Significant impacts of urbanization on the water cycle, and particularly on streamflow, have been reported since the 1960s, but there are differences between research studies. These differences reflect the influence of a number of biophysical catchment properties on rainfall-runoff processes, including (i) mean slope and mean elevation [39], (ii) lithology

Compared with agriculture and forest land-uses, urbanization decreases evapotranspiration [38] and groundwater recharge [38,43], and increases overland flow and stream runoff [44] (Figure 1). Decreased groundwater recharge often results from reduced infiltration in urban areas, but some studies report increases in groundwater recharge rates due to reductions in evapotranspiration linked to surface sealing or simply to reduced vegetation [45]. Increased runoff would have distinct impacts according with the catchment size. In small catchments, surface runoff is mostly driven by infiltration excess mechanisms linked to soil compaction/sealing, as a result of high intensity, short duration storms, thus leading to major impacts on flood peaks. In large catchments, however, the impact of soil compaction/sealing on floods is not so evident, since floods are often produced by saturation excess mechanisms, driven by extensive duration storms of lower intensity [46]. Urbanization reduces surface roughness of paved surfaces and usually comprises runoff piping through artificial systems, which favour flashiness and enhance hydrograph recession constant [43]. Urban streams, however, typically display reduced baseflow due to lower groundwater contributions [38,43], although sometimes water and sewer leakages within artificial drainage systems may enhance this streamflow component [44].

Urban areas comprise varying spatial mosaics of paved/sealed surfaces and green areas. Different combinations and spatial arrangements of impervious and pervious surfaces greatly affect the rainfall-runoff process, as well as the connectivity between land surface and the drainage network, and thus the speed and magnitude of runoff delivery to the stream [17,42]. For example, Ferreira et al. [47] recorded response times three times shorter in urban sub-catchments with continuously built-up areas located downslope, than with peaks and total streamflow than piping into adjacent areas of permeable soil [40]. Conventional piped drainage leads to four times greater runoff than a swale drainage system [19].

3.2 Deterioration of water quality and impacts on aquatic ecosystems

Pollutants deriving from urban areas include heavy metals [31], PCBs [47], nutrients [48], pesticides [44], pharmaceuticals [49] and faecal coliforms [50]. Sources of water pollution in urban areas can include (i) industrial processes and spills [51], (ii) untreated solid waste disposal and leachate from landfills [52], (iii) wastewater contamination from septic tanks, leakages in sewage systems and inefficient wastewater treatment [53], (iv) stormwater runoff [31,54], (v) lawns and gardens maintenance due to inappropriate fertilization and irrigation [55], (vi) soil erosion [56], and (vii) atmospheric deposition [30].

Runoff from urban areas has been considered a major non-point source of pollutants, namely due to high loads of heavy metals from roads [35] and rooftops [59]. The type of paving material (e.g. roads and roofs), the age and its conservation status influence the runoff composition and pollutant loads [60]. Spatio-temporal differences in road runoff composition are also driven by vehicular traffic, due to wear of vehicles components, such as tyres and brakes, as well as fluid losses [31], and gas exhaustion which can be transported and settled to urban surfaces through dry and/or wet deposition [35].

The type of urban pattern (e.g. isolated houses with gardens versus townhouses), including the presence or absence of urban drainage system, as well as the location of urban areas

Detached houses generate greater pollutant loads than high-density residential developments, due to greater extent of road surface and garden maintenance [55]. Main roads and industrial areas have been also associated with greater suspended sediments and heavy metals than residential and commercial areas [51].

Pollutants due to urbanization may decrease surface water and groundwater quality [44], and impair aquatic ecosystems [57,59] and water use for human consumption, irrigation and recreation [48]. Fine sediment has been considered a diffuse source of pollution due to its absorptive properties for several inorganic pollutants, such as phosphorus, heavy metals and PAHs in fluvial systems [53,56]. High sediment concentrations from urban areas may also increase surface water turbidity and reduce light penetration, with detrimental impacts on photosynthesis and, as a consequence, on dissolved oxygen and food availability to aquatic life in surface water bodies [60]. Sediment yields from newly urbanizing catchments tend to be 60 times higher than forest sediment yields and 11 times than agricultural sediment yields [58].

It is usually accepted that pollutant concentrations increase with percentage urban surface [54], thus urban cover has been used as an indicator of the ecological and environmental conditions of an aquatic system [48]. Generally, thresholds of 10% to 30% of impervious surface cover have been recorded to impair macroinvertebrate communities [59], which are widely used to assess the ecological status of the urban streams [56]. Nevertheless, some authors have been arguing that connectivity issues in urban catchments can be far more important for water quality than percentage of impervious surface [48]. In the context of the

4. Research challenges

Land degradation is a worldwide concern. Although there is a considerable research on the impacts of urban development on impairment of physical, chemical and biological soil and water properties and their impacts on ecosystem services, cause–effect relationships are not fully identified. Over the last decade, the role of hydrological connectivity has become a key issue in catchment hydrology, but the spatio-temporal variation of hydrological processes is not well understood [55]. The impacts of distinct urban patterns, characterized by different land-uses (e.g. residential, commercial, industrial) and varying mosaics of permeable and impermeable surfaces, on land degradation processes are rather complex. Outcomes to date have been inconclusive, particularly because of relatively scarce within-catchment data on erosion, hydrology and pollutant sources and processes. Further knowledge on the ability of distinct land-uses to absorb, release and/or transport different pollutants, and the connectivity between pollutant sources and water bodies requires further investigation. Knowledge on spatio-temporal dynamics of runoff and pollutant sources, as well as how connectivity governs water, sediment and pollutant flows within urban areas (site-scale) and catchment scale is a key research need.

Sediments may have negative consequences on aquatic ecosystems, but the impact of urbanization on sediment yields of urban catchments is poorly understood [61]. Long-term monitoring programs and complete national databases of soil erosion and contamination are required, together with long-term contamination risk assessments. Additional research on substances [63] is also required.

Recently, there has been a rising concern to integrate both grey and green infrastructures in urban areas, aiming to restore pre-development erosion, water and pollutant fluxes, as well as streamflow regimes and water quality. Nevertheless, implementation of nature-based solutions to enhance urban sustainability need to be supported by knowledge on land degradation processes at different scales.

Information on erosion, runoff and pollutant sources and pathways in different types of urban areas is fundamental to develop and implement cost-efficient strategies to improve streamflow regime and water quality. This knowledge is needed to guide policy actors, decision-makers and urban planners in developing more resilient cities and in implementing the most suitable solutions to achieve good ecological status of aquatic ecosystems.

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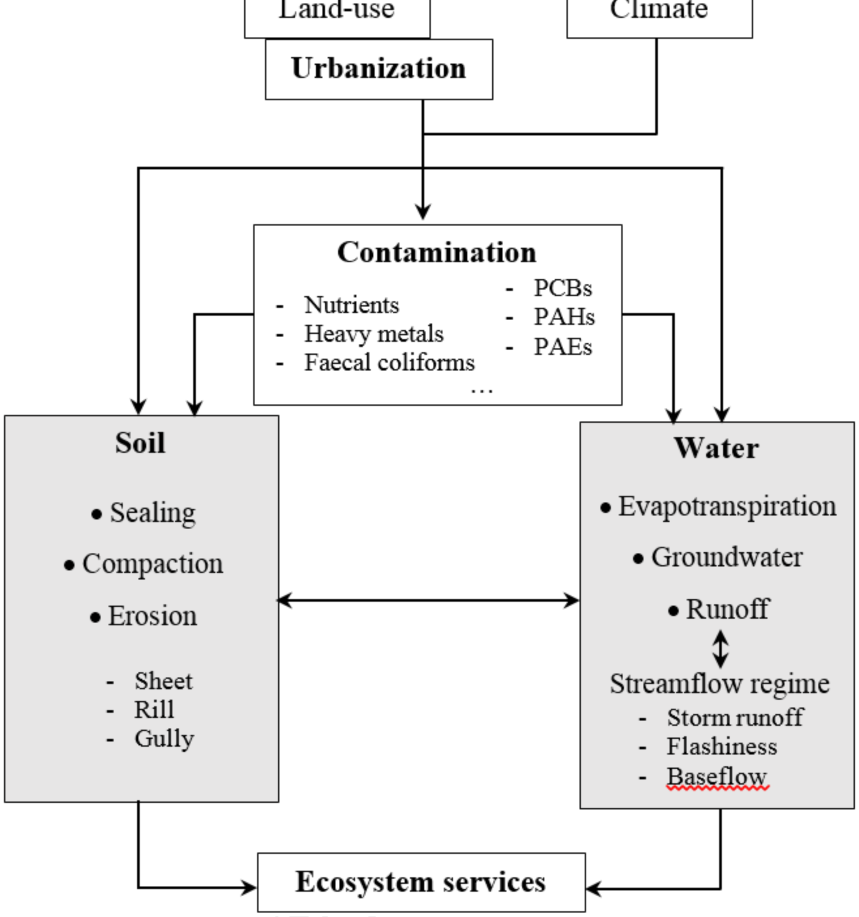

Figure 1 – Processes and variables influencing soil and water degradation in urban areas.

- Urban soils are subject to sealing, compaction, erosion and contamination
- Urbanization changes the hydrological processes and degrade water quality
- Urban patterns affect sediment and pollutants connectivity between sources and water bodies