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Review

A review of ion and metal pollutants in urban green water infrastructures

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HIGHLIGHTS

- Urban stormwater presents no sodicity and is suitable for irrigation.
- Urban dusts were highly polluted with metals, and possessed high ecological risk.
- Over 75% of metal pollutants can be retained by green water infrastructures (GWIs).
- For the first time, a metal biogeochemical cycle in GWIs has been proposed.
- Equilibrium and kinetic reactions of inorganic metals in GWIs have been described.

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ABSTRACT

In urban environments, the breakdown of chemicals and pollutants, especially ions and metal compounds, can be favoured by green water infrastructures (GWIs). The overall aim of this review is to set the basis to model GWIs using deterministic approaches in contrast to empirical ones. If a better picture of chemicals and pollutant input and an improved understanding of hydrological and biogeochemical processes affecting these pollutants were known, GWIs could be designed to efficiently retain these pollutants for site-specific meteorological patterns and pollutant load. To this end, we surveyed the existing literature to retrieve a comprehensive dataset of anions and cations, and alkaline and transition metal pollutants incoming to urban environments. Based on this survey, we assessed the pollution load and ecological risk indexes for metals. The existing literature was then surveyed to review the metal retention efficiency of GWIs, and possible biogeochemical processes related to inorganic metal compounds were proposed that could be integrated in biogeochemical models of GWIs.

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1. Introduction

The world population living in urban areas, currently about 50% (UNFPA, 2007; WB, 2012), is expected to increase to 60% by 2020 (UNESCO, 2003) and to 70% by 2030 (UNPD, 2002). The growing population and urbanization are responsible for an increased release of chemicals and pollutants into receiving water bodies (Gnecco et al., 2005; Pataki et al., 2011a). As a consequence, surface water quality has degraded as chemicals and pollutants are atmospherically deposited, and are conveyed by stormwater runoff (Ahiablame et al., 2012). Specifically, urban topsoils and dusts are known potential sources of transition metals at high concentration (e.g., Pb, Zn, Cu and Cd) (Akhter and Madany, 1993), which may also be washed out as soluble corrosion products of urban infrastructures (He et al., 2001).

There is a wide consensus on the necessity to develop urban systems that combine atmospheric pollution mitigation with water flow management, support soil phytoremediation and bioremediation (Clark and Pitt, 2012), and aid in managing water scarcity (Oberndorfer et al., 2007). To this end, green water infrastructures (GWIs), such as biofilters, vegetated open channels, permeable pavements, green roofs, and wetlands, have been indicated as an effective and sustainable way to tackle these issues in urban areas (Getter and Rowe, 2006; Oberndorfer et al., 2007; Van Seters et al., 2009; Kaspura, 2010; Stovin et al., 2012).

Soil media are one of the most important components of GWIs. Various soil biogeochemical processes that degrade chemical pollutants occur due to the presence of water, microorganisms, minerals, nutrients and plants (Monterusso et al., 2004; Peters et al., 2008; Alsup et al., 2010). Although a greater research effort has been devoted to the understanding of soil biogeochemistry in agriculture and silviculture (Lehmann and Stahr, 2007), and only recently on global climate and soil change (Lorenz and Lal, 2009; Pataki et al., 2011b; Zaehle and Dalmonech, 2011; Blagodatsky and Smith, 2012; Pokrovsky et al., 2012), it is natural to extend those efforts to the biogeochemical functions that GWIs can exert in urban environments. For example, models describing stormwater quality (Obropta and Kardos, 2007), soil moisture dynamics (Hilten et al., 2008; Stovin et al., 2012), and soil C and N biogeochemistry (Lorenz and Lal, 2009; Manzoni and Porporato, 2009; Batlle-Aguilar et al., 2011) may be adapted to the urban environments if a more detailed knowledge of chemical input (such as species and rates), and biogeochemical soil functions become available. Thus, we believe that there is a great potential to investigate how these models may be used in designing effective GWIs.

The objectives of this paper are: (1) surveying urban pollutants, specifically ions and metals incoming in GWIs, (2) analysing the potential of urban GWIs to retain and degrade pollutants, and (3) proposing soil biogeochemical processes relevant to GWIs to optimize their design.

2. Urban pollutants

Deposition of pollutants in an urban environment is correlated to atmospheric pollutants, which include particulate, dusts, powders, debris, as well as aerosols and gases (Beysens et al., 2006). These can have origin within the urban setting itself, such as from benzine-fuelled vehicles, tyres wearing, household wastes, and industrial activities, as well as being advected from far away. Sources of atmospheric pollution, and related processes and effects, can be found in Elsom (1987), and are not treated here.

Pollutants set down in urban environments by dry and wet deposition. Dry Deposition (DD) occurs by gravitational settling of particles in the form of dusts and colloidal particulate, whereas wet deposition occurs in the form of rain, dew and fog. The chemical concentration in wet deposition is generally very low in a non-urban environment, while rain droplets encounter various particles suspended in the urban atmosphere and dry-deposited atmospheric pollutants, thereby leading to high chemical concentration. Wet Deposition and Runoff (WDR) therefore include components resulting from dry and wet deposition, and are the major carriers of chemicals and pollutants (specifically, ions and metals) in urban environments. Depending upon oxygen exposure, pH, moisture content, presence of chemical ions, and microorganisms, metals can precipitate in the form of oxides, hydroxides, carbonates, and sulphides, which can bond with other chemicals and may result in metal complexes that may be buffered in the soil (Violante et al., 2010).

Urban pollutants also include microbes as biologically derived contaminants, which may be originated from various sources such as faecal materials, dead animals, plant debris, and contaminated surfaces (Abbasi and Abbasi, 2011). In urban stormwater, *E. coli*, is an indicator organism of faecal pollution commonly used for health risk assessment when using stormwater as an alternative water resources (McCarthy et al., 2007). However, the microbial biodiversity in an urban setting is very wide and a full taxonomy of biological presence and contamination is currently missing and beyond the purpose of this work.

Within the context of this review, we focused on urban pollutants in WDR and DD of ionic and metallic nature, including inorganic compounds of alkaline and transition metals. We surveyed 90 datasets from the existing literature and carried out a statistical analysis for comparison with freshwater and irrigation water standards used in Europe, Oceania, and the USA, and with respect to the level of soil background pollution in the world. The data were from all over the world and were therefore very scattered in terms of geographic locations. This may imply a large variability due to different climatic regions, hydrological regime, urban setting and exposure to pollution sources, as well as density of data. In spite of this, the number of samples was large enough to produce a picture of the amounts and species of pollutants in urban areas.

2.1. Ion concentration in wet deposition and runoff

A comprehensive literature survey of incoming ions in urban GWIs resulted in 46 datasets relative to WDR for one to ten ions per sample

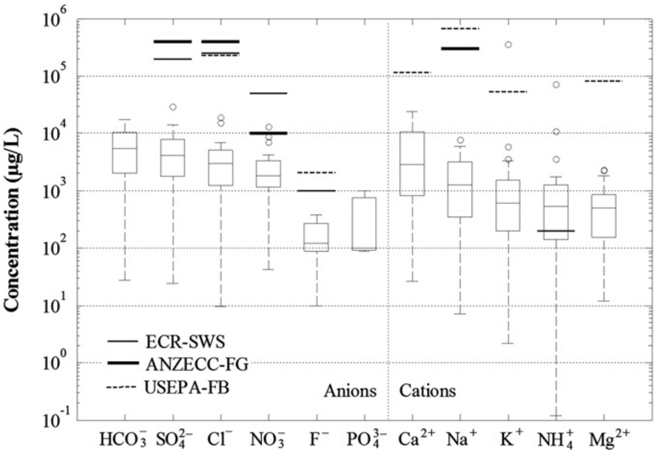

Fig. 1. Ion concentration in urban WDR samples.