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Towards a better identification of contaminant retention mechanisms in SUDS soil: Zr deficit as a tracer of sediment accumulation

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KEYWORDS

Contamination, Runoff infiltration, Sediment, Spatial distribution, Sustainable Urban Drainage Systems, X-ray Fluorescence

SUMMARY

Among the processes governing contaminant retention in soil-based SUDS, the relative contribution of particle settling and filtration is not always properly identified. Since zirconium is a well-documented invariant in pedology, the present work aimed to assess whether its use might be extended to sediment identification in SUDS. Extensive sampling and analysis were carried out in 11 infiltration systems. Zr contents were found to be significantly lower in road-deposited sediment than in soil. A deficit of this element could also be observed in the most contaminated area of most devices, indicating a “dilution-like” mixture of soil and sediments, the fraction of which could be calculated.

INTRODUCTION

In addition to their widely recognized hydrologic and hydraulic improvements, Sustainable Urban Drainage Systems (SUDS) offer interesting perspectives towards the interception of diffuse pollutant fluxes in urban environments (Napier *et al.*, 2009). The soil's retention potential originates from both physico-chemical and physical mechanisms, *i.e.* the sorption of contaminants onto various reactive constituents of the soil matrix, and the deposition and filtration of particle-bound species, respectively. Hence, the spatial variability of heavy metal contents in the surface soil of SUDS has been demonstrated to provide a time-integrated pattern of both non-uniform infiltration fluxes and settling processes within a device (Tedoldi *et al.*, 2017). However, identifying the contribution of each mechanism to the overall contaminant retention remains a complex issue.

In pedological approaches, Zr is often taken as a geochemical invariant, due to its very low mobility in soils, the absence of anthropogenic sources, and its relative abundance in most soils (Egli and Fitze, 2000; Schulz, 1965). The objective of the present work is to assess the potential use of Zr as an unequivocal tracer of sediment accumulation in SUDS, based on high-resolution soil sampling and analysis from 11 infiltration systems.

MATERIALS & METHODS

Four infiltration basins, five swales, and two filter strips, with contrasting hydraulic configurations, watersheds, and runoff contamination potentials, were selected as study sites. Extensive sampling

campaigns were undertaken, collecting both surface (> 35 points/100 m²) and core samples. Whenever possible, additional samples of raw sediment were taken on the nearby road pavement. After drying, sieving and homogenization of the samples, elemental analysis was performed *via* X-ray fluorescence spectrometry (*Thermo Scientific*, Niton™ analyzer XL3t), including well documented urban- or traffic-derived metals (Cu, Pb, Zn) and Zr. Surface contents were interpolated so as to generate cartographies.

RESULTS & DISCUSSION

In every study site, surface contamination (related to Cu, Pb and Zn) was characterized by a significant buildup near the inflow zone, followed by a marked decrease in metal contents with increasing distance (Figs. 1 and 2). This observation, the implications of which have been thoroughly discussed elsewhere (Tedoldi *et al.*, 2017), provided evidence of a localized area affected by runoff-derived contamination. Remarkably, Zr commonly displayed “mirror” distributions, *i.e.* a deficit in the most contaminated zone, with a reverse increasing trend toward the uncontaminated part of the devices (Figs. 1 and 2). In 7 sites out of 11, the (negative) correlations between Zr and Cu, Pb or Zn were statistically significant with $p < 10^{-3}$. The other facilities were implemented in catchments with *a priori* low suspended solid production (residential areas, lightly trafficked roads).

Because of its low mobility in soils, Zr is not likely to have been lixiviated from the upper horizons by the infiltrating water. Hence, the peculiar deficit observed near the inflow zone may be explained by the fact that the collected samples were actually a mixture of soil and sediment with different elemental compositions. In the examples displayed on Figs. 1 and 2, Zr contents found in the non-contaminated part of the devices ranged from 650 to 700 mg/kg, while they were 185-210 mg/kg in the road-deposited sediments. Within the devices, Zr contents lied between these extreme values, indicating a “dilution” of soil by the sediment, so that analyzed concentrations C may be written as:

$$C = fC_{\text{sediment}} + (1 - f)C_{\text{soil}}$$

where C_{sediment} and C_{soil} are the Zr concentrations in raw sediment and soil, respectively, and f is the sediment fraction. The spatial distribution of the coefficient f was thus determined at the surface of the sites with significant correlations between Zr and metals (Fig. 3). When applied to soil cores, this method enabled the quantification of filtered particles along vertical profiles – provided the geochemical background was fairly uniform with depth.

Non-homogeneous humus formation might also participate in this “dilution”. Volatile matter was quantified in every collected sample *via* 6-h calcination at 550°C, but its variability in the surface soil was generally not sufficient to explain the observed Zr deficit (Fig. 4). In roadside swales, no significant trend could be observed with respect to the distance from the road.

CONCLUSIONS

In the catchments with significant suspended solid production (*e.g.* highways or industrial areas), zirconium, whose contents are lower in sediment than in soil, has been proven to characterize the sediment-based “dilution” of the samples collected in infiltration-based SUDS. It is then possible to assess the amount of deposited and/or filtered particles, and thus to identify the contribution of mechanical processes to the overall retention of urban-derived contaminants.

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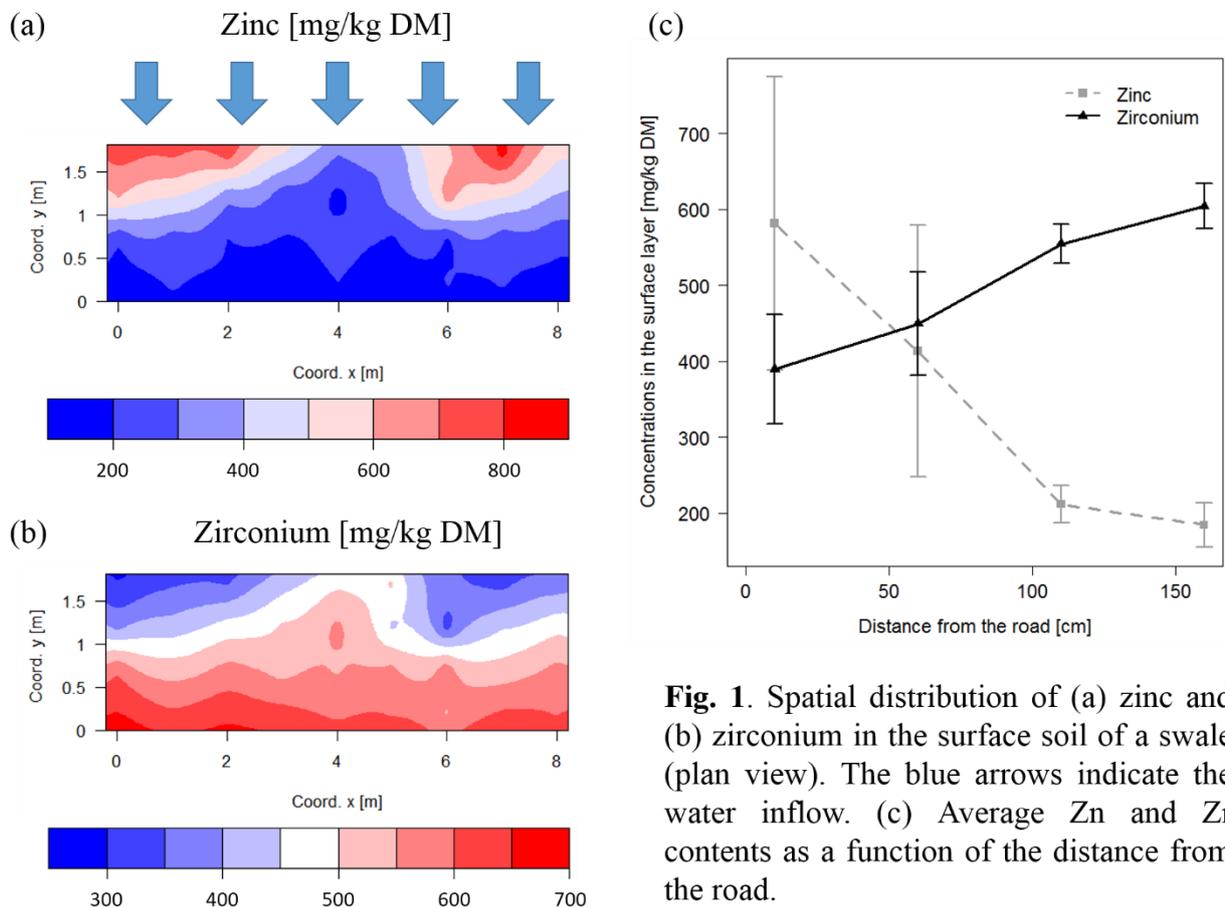


Fig. 1. Spatial distribution of (a) zinc and (b) zirconium in the surface soil of a swale (plan view). The blue arrows indicate the water inflow. (c) Average Zn and Zr contents as a function of the distance from the road.

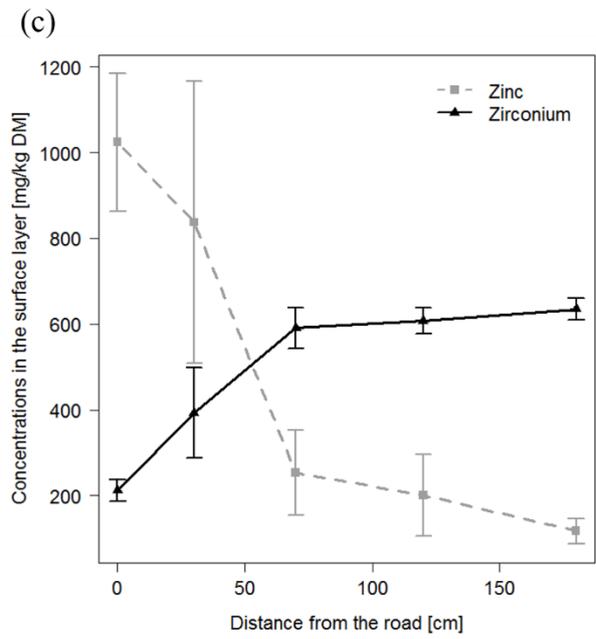
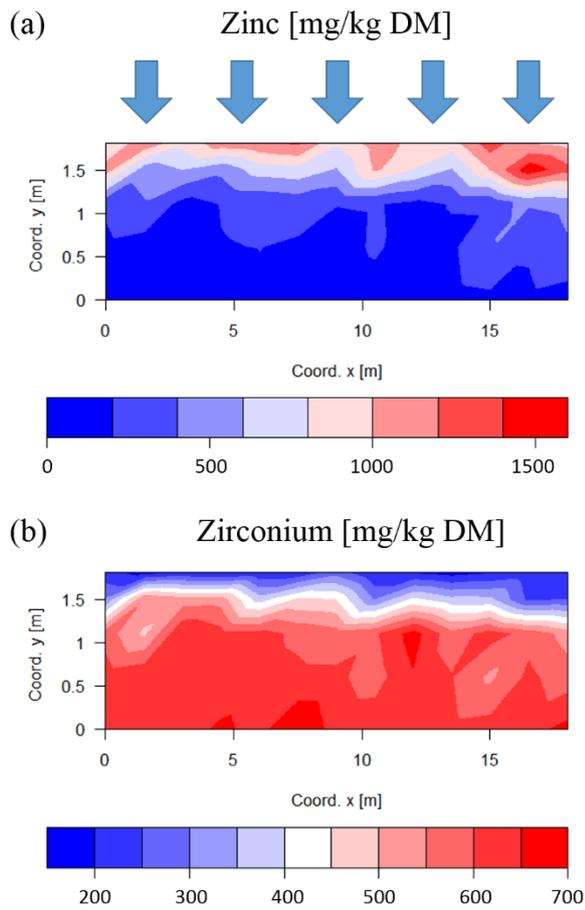


Fig. 2. Spatial distribution of (a) zinc and (b) zirconium in the surface soil of a roadside filter strip (plan view). The blue arrows indicate the water inflow. (c) Average Zn and Zr contents as a function of the distance from the road.

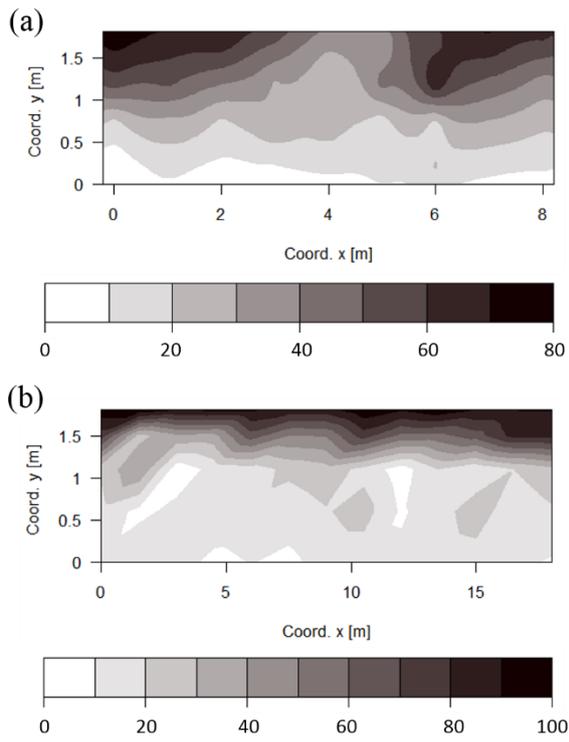


Fig. 3. Calculated fraction of sediments [%] in (a) the swale and (b) the filter strip.

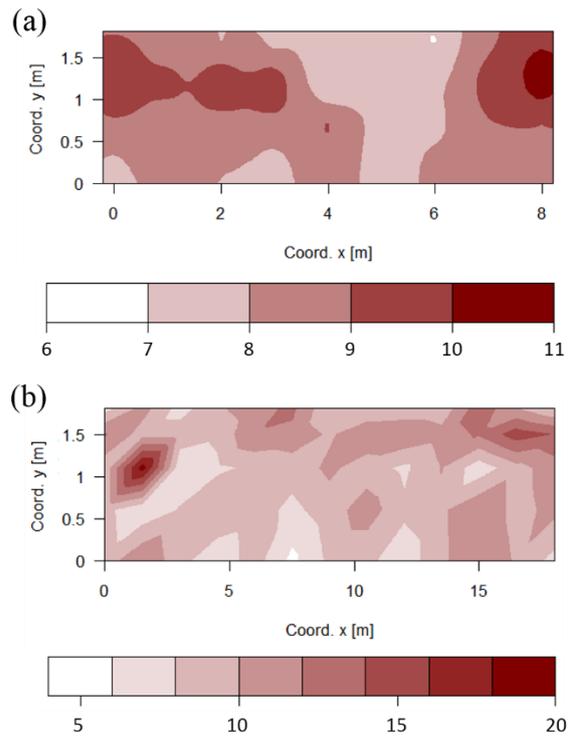


Fig. 4. Volatile matter content [%] in the surface soil of (a) the swale and (b) the filter strip.