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Geochemical signature of urban stormwater sediments: a France/Sweden comparison

Signature géochimique des sédiments de bassins pluviaux : une comparaison France/Suède

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ABSTRACT

Detention- and infiltration-based systems for stormwater management trap runoff particles, which gradually form a sediment layer loaded with multiple contaminants. This study examines the trace metal composition of stormwater sediments, through a comparison between French and Swedish infrastructures. Composite sediment samples were collected from 18 infiltration basins in France and 17 wet ponds in Sweden, the catchments of which encompass a diversity of urban and sub-urban contexts. Zinc and copper were consistently more concentrated in sediments than the baseline levels in local soils, while this was not always the case for the other metals in Sweden. Overall, contamination levels were higher in the French sites: median Pb, Cu, and Zn concentrations were respectively 154, 152, and 570 mg/kg in France, and 19, 46, and 178 mg/kg in Sweden. This difference may be due to the functioning of the devices (infiltration vs. detention), but also suggests a possible “dilution” of runoff suspended solids in the Swedish catchments. The latter may originate from crushed traction grit or eroded soil particles, as some of the least polluted Swedish ponds had a relatively high share of permeable surface in their catchments. The geochemical signature of stormwater sediments was also found to be different between the two countries, as illustrated by the different ratios between metals, indicating dissimilarities in emission sources.

RÉSUMÉ

Les ouvrages de rétention et d'infiltration des eaux pluviales interceptent les matières en suspension, qui forment progressivement une couche de sédiments poly-contaminés. Cette étude s'intéresse à la composition en métaux traces de ces sédiments, en comparant des infrastructures situées en France et en Suède. Des échantillons composites de sédiments ont été prélevés dans 18 bassins d'infiltration en France et 17 bassins de rétention en Suède, dont les bassins versants représentent une diversité de contextes urbains et péri-urbains. En comparaison du bruit de fond anthropisé des sols environnants, le zinc et le cuivre étaient systématiquement plus concentrés dans les sédiments, mais ce n'était pas toujours le cas pour les autres métaux en Suède. Les niveaux de contamination étaient globalement plus élevés dans les sites français : les teneurs médianes en Pb, Cu, et Zn étaient respectivement de 154, 152, et 570 mg/kg en France, et de 19, 46, et 178 mg/kg en Suède. Cette différence peut s'expliquer par le mode de fonctionnement des bassins (infiltration vs. rétention), mais suggère également une possible « dilution » des matières en suspension sur les bassins versants suédois, due à des graviers de traction broyés ou des particules de sol érodées. Les sédiments des deux pays présentaient une signature géochimique différente, comme l'illustrent les ratios entre métaux, ce qui indique des différences dans les sources d'émissions en France et en Suède.

KEYWORDS

Detention, Infiltration, Metals, Ratios, Sediments, Sustainable Drainage Systems.

MOTS-CLÉS

Gestion durable des eaux pluviales, Infiltration, Métaux, Ratios, Rétention, Sédiments.

1 INTRODUCTION

Stormwater management in urban areas increasingly involves detention- and/or infiltration-based systems. Not only do these facilities bring hydraulic and hydrological improvements (e.g., by alleviating the sewer system and contributing to the restoration of a more “natural” water balance), but they also offer various co-benefits such as the mitigation of contaminant fluxes. In particular, suspended solids conveyed by stormwater runoff can be intercepted through settling and/or filtration (Arthur, 2020), gradually forming a layer of “*stormwater sediments*” at the bottom of the device (El-Mufleh *et al.*, 2014), also referred to as “*surface deposits*” in infiltration basins.

Besides having reactive properties, runoff particles are loaded with a range of inorganic and organic substances, as a result of which stormwater sediments exhibit multiple contamination (Crane, 2019; Crawford *et al.*, 2010; Flanagan *et al.*, 2021). Our working hypothesis is that these sediments, as a consequence of an accumulation process that mitigates the variability of concentrations in runoff, provide an integrated view of contaminant emission sources within the drained catchment. The core objective of this study was therefore to compare the geochemical signatures of stormwater sediments between French and Swedish devices, with a focus on trace metals.

2 MATERIAL & METHODS

2.1 Site description

Sediment was collected from 17 facilities in Sweden and 18 in France, draining stormwater from a wide diversity of urban and sub-urban catchments (industrial, residential, and road/parking lot). Swedish sites correspond to wet ponds located in 4 different municipalities. They were constructed between 1988 and 2010 and all designed with an objective of treating urban stormwater through sedimentation. Catchment size varied from ~1 to 1490 ha; facility-to-catchment ratios were between 0.007 and 2.6%.

French sites correspond to dry infiltration basins in the *Greater Lyon* conurbation – an area with a high permeability that has led to the widespread implementation of infiltration facilities for stormwater management since the mid-1970s. Most basins had been in operation for ≥ 10 years when sampling campaigns were carried out, and the last dredging operation (if any) had been undertaken ≥ 5 years ago. Catchment size varied from 2 to 434 ha, with a facility-to-catchment ratio between 0.1 and 1.2%.

Three studied locations in Sweden (Stockholm, Örebro and Växjö) have humid continental climate (Köppen climate classification code Dfb) while pond in Östersund has subarctic climate (Dfc). The *Greater Lyon* area has a semi-continental climate (Cfa).

2.2 Sediment sampling

In the Swedish ponds, sediment samples were collected at system inlets and outlets using a Kayak core sampler (KC Denmark) with a stainless-steel liner. At each location, several cores were collected to obtain a 3-L composite sample of sediment. Cores were placed in a stainless-steel tray, mixed, then divided into aliquots for the different analyses.

A similar approach was applied in the French infiltration basins, however with one composite sample per facility. Subsamples were collected at 8 to 20 locations depending on the basin size, uniformly distributed over the sediment layer. The latter was easily distinguished from the underlying soil (marked color transition and different texture); it was sampled over its entire depth – which varied between a few centimeters and ≥ 20 cm – using a stainless-steel shovel or a hand auger. This composite sample obtained after mixing all subsamples was then quartered on the field and divided into aliquots.

2.3 Sediment analysis

Among the common analyses that were carried out on the sediment samples, the present study will focus on trace metals (Cr, Cu, Ni, Pb, and Zn), as well as general parameters including pH, total organic carbon, and loss on ignition. Pseudo-total contents of metals were determined after sieving at < 2 mm and acid digestion (heat-assisted digestion with 7M HNO₃ for the Swedish sites, and *aqua regia* (HCl + HNO₃) digestion for the French sites). All concentrations are expressed in milligram of metal per kilogram of dry matter. As two samples (inlet and outlet) were analyzed from the Swedish facilities, in order to facilitate comparison with the samples from the Lyon campaign, a facility mean concentration is used for the rest of this study.

3 RESULTS & DISCUSSION

3.1 Evidence of a catchment-induced contamination

The concentrations of metals in sediments from French and Swedish devices are presented on Figure 1. As a first basis for comparison, these values were put into perspective with the usual ranges of metal contents in local soils – available from the *French database on trace metals* (“BDETM”) and the *Geochemical atlas of Sweden*. It was considered that exceeding the 9th decile of usual contents could reasonably be attributed to site-specific sources of contamination.

Sediments from almost all French basins displayed higher metal concentrations than the baseline levels in the *Greater Lyon* area. Conversely, in sediments from Swedish ponds, concentrations of nickel, chromium, and lead, fell more frequently within common soil values. For instance, in surface soils from the County of Stockholm, the 9th deciles for Ni, Cr, and Pb are respectively 24, 50, and 21 mg/kg; between the 6 sites from this area, 4 displayed concentrations below these values. This occurred for 2/6 sites in Örebro, and 2/4 sites in Växjö. However, copper- and zinc-related contamination was almost consistently ascertained, with more than two-thirds of the sites exceeding the 99th percentile for Zn.

Among the French (resp. the Swedish) devices, no difference between catchment types could be demonstrated, whatever the metal (Kruskal-Wallis test, p -value > 0.1). In other words, the predominant land use of the drained catchment is not a reliable predictor of sediment contamination, as previously observed by Flanagan *et al.* (2021) and Gavrić *et al.* (2022). However, the sites from the two countries did show some differences which are subsequently described and discussed.

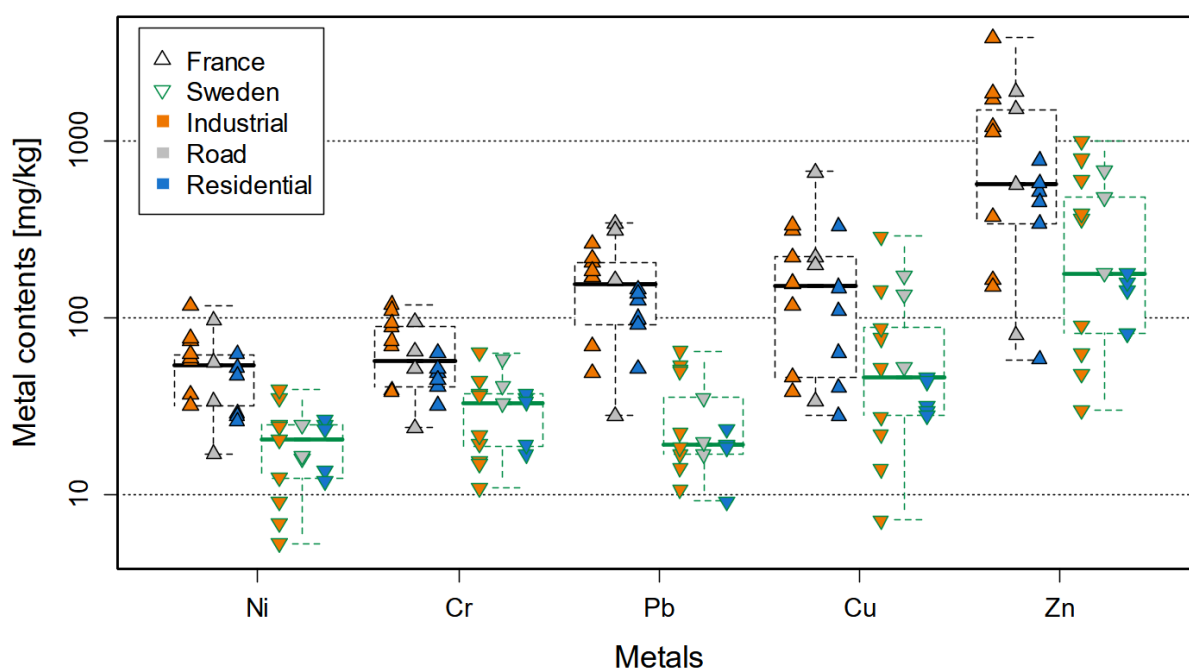


Figure 1 – Metal concentrations in the sediments from the French (black) and Swedish (green) sites.

3.2 Different geochemical signatures between French and Swedish sediments

Metal concentrations in the Swedish ponds were globally lower than in the French basins (Figure 1). Median values differed by a factor of 1.7 to 8, with, e.g., 19 mg/kg for Pb, 46 mg/kg for Cu, and 178 mg/kg for Zn in Sweden, and respectively 154, 152, and 570 mg/kg in France. Regardless of the metal, the observed differences between the two countries were hardly compatible with the hypothesis of the same parent distribution (Wilcoxon-Mann-Whitney test, p -value < 0.02). So as to contextualize these differences, it should first be kept in mind that French sites are infiltration-based systems – without any surface outlet – whereas Swedish sites are detention/settling facilities that may not trap all runoff particles. Another hypothesis to explain this dissimilarity corresponds to the widespread application of traction grit in Sweden during winter: although the grit is coarse and unlikely to be transported by runoff, road traffic can grind it into smaller particles that may induce a “dilution” of the sediments. Dilution may also originate from soil particles eroded from permeable surfaces, as some of the least polluted Swedish sites had a catchment area with relatively low imperviousness (5-40%).

The comparison was extended to ratios between elements (Figure 2). While zinc was usually 2.5 to 4 times more concentrated than copper in sediments from both countries, several French sites exhibited a significant enrichment of zinc, with Zn/Cu ratios between 8 and 16: this can be explained by different building materials, and notably an extensive use of zinc in roofs and gutters within these catchments. Copper and lead were found in relatively comparable amounts in French sediments, whereas Cu/Pb ratios revealed a relative depletion of Pb in the Swedish sites: this may be due to an earlier phase-out of leaded gasoline (especially for the road environments), but also to the fact that in Sweden, lead is not used on building exteriors to the same extent as in France (e.g., for sealing elements on roofs). Similarly, Cr/Ni ratios were lower in France than in Sweden, also suggesting differences in emission sources.

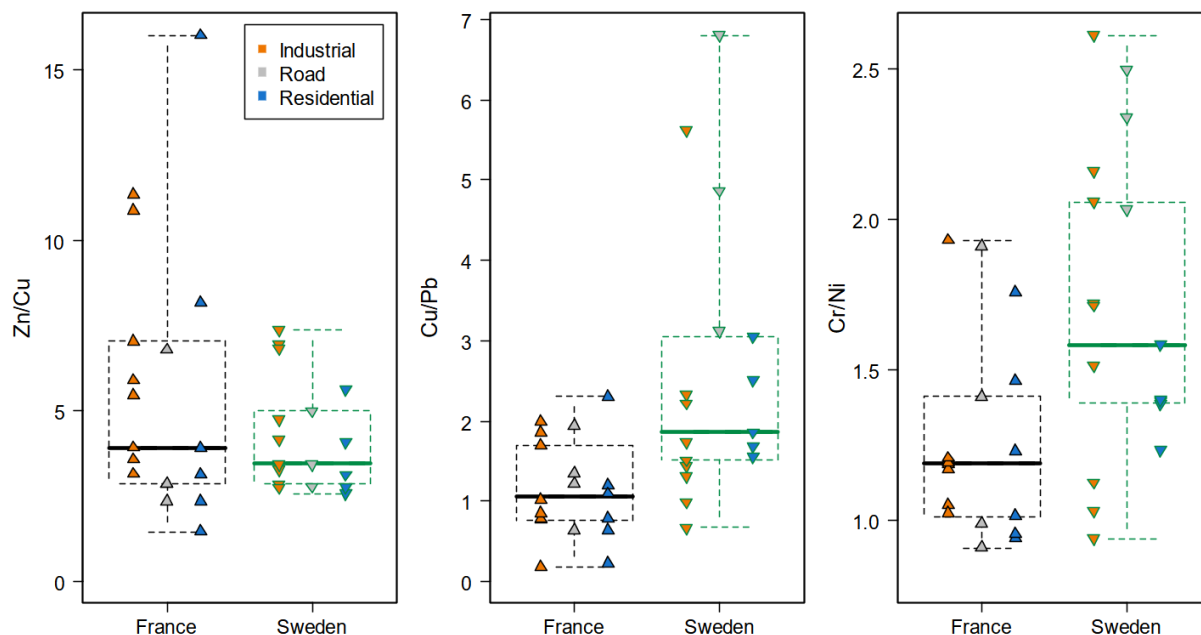


Figure 2 – Ratio between metals in the sediment samples from the French (black) and Swedish (green) sites.

4 CONCLUSIONS & PERSPECTIVES

This study explored the metal composition of accumulated sediments in Sustainable Drainage Systems through a France/Sweden comparison. In both countries, the accumulation of zinc and copper undoubtedly constituted the signature of urban contamination, while the situation was more contrasted for lead, chromium, and nickel. Contamination levels were globally higher in French sites, with different ratios between metals suggesting dissimilar emission patterns. Among the possible reasons for such differences, the impact of different driving conditions due to snow (e.g., use of traction grits or studded tires) will be further explored. Additional perspectives include the search for geochemical tracers of runoff suspended solids and “other” particles such as eroded soil.

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