
Evaluating low-cost proxies for contamination in stormwater sediments

Évaluation de proxys peu coûteux pour la contamination des sédiments de ruissellement pluvial

Merethe A. Strømberg¹, Haoyu Wei², Alexandra Müller², Lisa Gren³,
Kelsey Flanagan², Tone Merete Muthanna^{1,2,4}, Maria Viklander²

¹Norwegian University of Science and technology

²Luleå University of Technology

³IVL Swedish Environmental Research Institute

⁴Rambøll

*Corresponding author: merethe.stromberg@ntnu.no

RÉSUMÉ

Les sédiments des eaux pluviales urbaines peuvent accumuler un large éventail de contaminants, tandis que les municipalités manquent souvent de ressources pour des analyses de laboratoire approfondies permettant d'en définir la gestion appropriée. Cette étude évalue l'analyse de la couleur, la fluorescence X (XRF) et la microscopie optique comme méthodes à bas coût pour caractériser les sédiments et identifier des sources de particules anthropiques. L'évaluation s'appuie sur des échantillons provenant de 17 bassins d'eaux pluviales et de 26 avaloirs en Suède, déjà analysés pour les métaux et contaminants organiques. L'analyse de la couleur a montré des variations spatiales pour les sédiments des bassins : des niveaux plus faibles de polluants et des couleurs plus claires à Örebro, tandis que les sédiments plus sombres de Växjö et Stockholm présentaient des concentrations plus élevées, indiquant le potentiel de la couleur comme indication préliminaire de pollution. L'analyse microscopique a révélé divers matériaux anthropiques, fibres textiles, plastiques, fragments métalliques, billes de verre, mettant en évidence les contributions de plusieurs sources distinctes. À l'inverse, les sédiments d'avaloirs présentaient des relations plus faibles entre couleur, métaux et polluants, probablement en raison de différences dans les caractéristiques des bassins versants. Dans l'ensemble, ces méthodes ont fourni des informations utiles sur la composition et les modes de contamination des sédiments, mais des analyses complémentaires restent nécessaires pour confirmer les tendances observées entre couleur et niveaux de polluants.

ABSTRACT

Urban stormwater sediments can accumulate a broad range of contaminants, yet municipalities often lack the resources for extensive laboratory analyses to determine appropriate management of these sediments. This study evaluates colour analysis, X-ray fluorescence (XRF), and optical microscopy as low-resource methods for characterising sediments and identifying anthropogenic particle sources. The assessment used sediment samples from 17 stormwater ponds and 26 gully pots in Sweden, which were earlier examined for metal and organic contaminants. The colour analysis showed spatial patterns for stormwater pond sediments, with lower anthropogenic pollutant levels and lighter colours in Örebro and darker sediments from Växjö and Stockholm showing higher pollutant concentrations, indicating the potential for colour as preliminary pollution indication. Microscopy revealed different anthropogenic materials, including clothing fibres, plastics, metal fragments, and glass beads, highlighting multiple contributing sources. In contrast, gully pot sediments displayed weaker relationships between colour, metals and pollutants, likely due to difference in catchments characteristics. Overall, the combined methods provided valuable insights into sediment composition and contamination patterns, however, further analysis is needed to confirm the observed trends of colour and pollutant levels.

KEYWORDS

Urban stormwater, stormwater ponds, gully pots, sediment quality, anthropogenic pollutants

1 INTRODUCTION

Urban stormwater runoff transports a wide range of contaminants originating from various anthropogenic activities and sources (e.g. Wicke et al. (2021)) that accumulate within stormwater control measures such as gully pots (GPs) and stormwater ponds. Over time, substantial quantities of sediments accumulate within these SCMs, necessitating routine maintenance to preserve hydraulic function and treatment performance. The resulting sediment characteristics can be highly variable and sometimes heavily contaminated, creating challenges for accurately and robustly evaluating the environmental risks posed by this material, both during operation and at the time of their removal for maintenance and disposal.

Fully characterizing the contamination requires extensive analytical work across a broad range of substances, yet municipalities often lack the resources to perform such assessment routinely. Substantial variations in contaminant profiles across SCM types and locations (e.g. Flanagan et al. 2021; Wei et al. 2023) further increase the need for developing resource-efficient approaches that can support or complement chemical analyses. Flanagan et al. (2021) observed that stormwater pond sediments in one city (Örebro) had significantly lower contaminant concentrations and exhibited distinct colour differences compared to sediments collected in other cities. This study therefore aims to evaluate the potential of less resource-intensive approaches, including colour analysis, metal ratios, and microscopy, as proxy indicators of anthropogenic contamination levels in stormwater sediments.

2 METHOD

2.1 Study area and sampling

Sediments from 17 stormwater ponds across four Swedish municipalities - Örebro (Or), Östersund (Os), Stockholm (S) and Växjö (V) - were collected in 2019 and analysed for organic contaminants (Flanagan et al., 2021) and metals (Gavrić et al., 2022). The ponds drain urban and sub-urban catchments with varying land uses (industrial, residential, road or highway) and differ widely in facility ages (constructed 1988-2010), catchment size (~1 to 1490 ha) and facility-to-catchment ratios (0.007 and 2.6%). The samples were taken at the inlet ("in") and outlet ("out") using a Kajak sediment core sampler (KC Denmark). Multiple cores were collected per location and homogenised into composite samples. Further details on study areas and sampling procedure are detailed in Flanagan et al. (2021). Additionally, sediment samples from 26 gully pots (GPs) located in Stockholm, Sweden were analysed for 101 organic substances. These GPs drain catchments comprising parking lots, commercial areas, pedestrian/bike paths, and residential areas. Samples were collected from the full depth of each GP and homogenised into one composite sample. More methodological information is provided in Wei et al. (2023).

2.2 Sediment characterisation

Metal concentrations (Cd, Cu, Zn, Pb, Zr) in the stormwater sediments were determined using a handheld X-ray fluorescence (XRF) analyser (Thermo Scientific Niton XRF Portable Analyzer). Freeze-dried samples were ground to a fine material, placed in small bags and analysed in triplicate with a 120-second measurement time. The sample bags were mixed between measurements. For measurements below the limit of detection (<LOD), concentrations were set to three times the standard deviation. Sediment colours were assessed using the Munsell Soil Colour Scale by matching each sample to corresponding colour chips. Both freeze-dried and re-wetted samples were initially examined; however, freeze-dried samples exhibited greater colour differentiation and were used for subsequent assessments. To minimise subjective colour perception, colours were grouped into five categories: light grey, grey, brown, olive brown, and black. Stormwater pond sediments were further examined under an optical microscope (Nikon SMZ-U). Small amounts of sediments were placed on petri dishes and examined at varying magnifications. Images were taken to document the general structure and deviations.

3 RESULTS AND DISCUSSION

3.1 Metal ratios

To partially account for background concentrations in local soils, the XRF measurements were normalised using county-specific background levels from the Geochemical atlas of Sweden. Figure 1 shows the ratios for Zr and Zn in stormwater pond sediments. Zr has few anthropogenic sources and therefore has been proposed as a marker of non-urban influence (Tedoldi et al., 2018), whereas Zn is typically enriched by urban activities, such as tyre wear and galvanised materials. Consequently, a higher Zn ratio together with a lower Zr ratio is interpreted

as indicating a greater degree of anthropogenic influence. The Örebro (Or) sediments are among the highest Zr ratios and the lowest Zn ratios (Figure 1), indicating a comparatively low anthropogenic influence. This aligns with the findings in Flanagan et al. (2021) and Gavrić et al. (2022), where samples from Örebro (Or) had the lowest concentrations of organic contaminants and metals.

The differences between Örebro and the other locations could not be attributed to catchment land use characteristics (Flanagan et al., 2021). Instead, it was hypothesised that soil erosion in open channels upstream of the sediment ponds contributed to a larger proportion of natural material, in contrast to the more closed systems at the other locations. Under this hypothesis, elevated Zr ratios may indicate a greater soil fraction and dilution of anthropogenic contaminants, whereas higher ratios of Zn, Cu, and Pb, identified in Stockholm and Växjö indicated stronger urban influences and correspondingly lower Zr ratios.

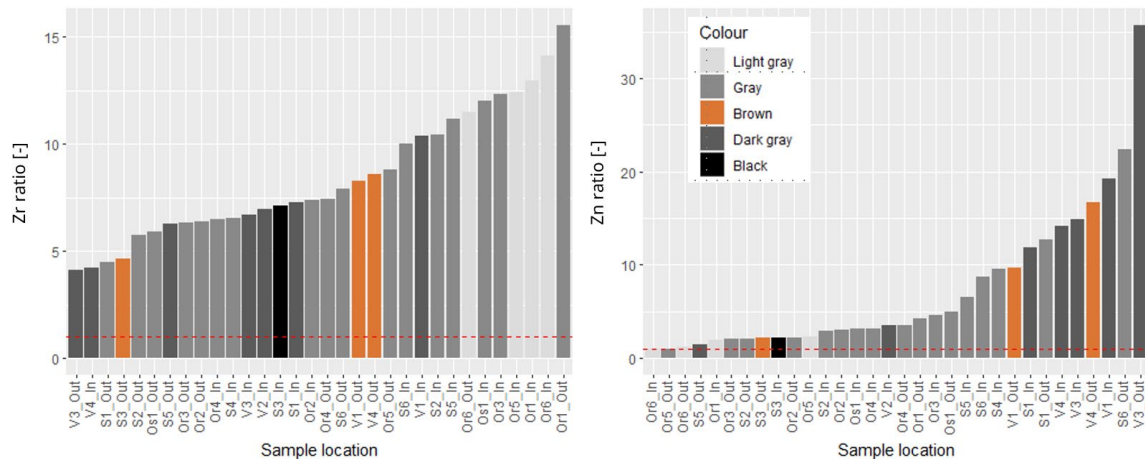


Figure 1: Ratios of Zr and Zn (XRF concentration normalised to county background levels) for stormwater pond sediments, sorted in ascending order and grouped by sediment colours. Sample locations are indicated by municipality: Örebro (Or), Östersund (Os), Stockholm (S) and Växjö (V). The red dotted line represents a ratio of 1.

3.2 Colour

Colour analysis of stormwater pond sediments revealed that concentrations of many substances differed significantly between colour groups, with selected examples presented in Figure 2. Several substances showed significantly higher concentrations in the dark grey sediments, including hydrocarbon aliphatic (>C16-C35), di-(2-ethylhexyl) phthalate (DEHP) and Zn, all commonly associated with urban sources.

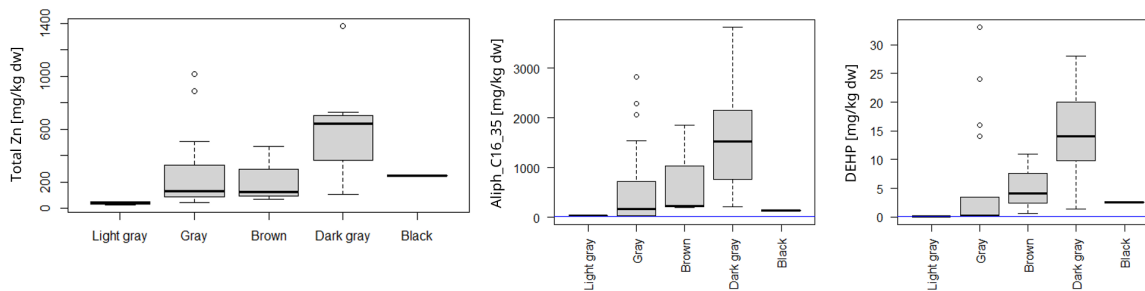


Figure 2: Boxplots showing the concentration of Total Zn, Aliphatic C16-C35 and DEHP grouped by sediment colour for stormwater pond sediments. Blue line for organic pollutants indicates the limit of detection.

As for the metal ratios examined earlier, light grey sediments were frequently associated with higher Zr ratios (Figure 1), suggesting that these samples contained a greater proportion of natural soil material. By contrast, dark grey sediments more often corresponded to higher Zn ratios, indicating a comparatively stronger anthropogenic influence.

Overall, the colour analysis indicates stormwater pond sediments with that darker colour tend to exhibit higher contaminant concentrations, with the exception of black sediments. During sampling, the black sediments were described as peaty (Flanagan et al., 2021), indicating higher levels of natural organic matter. This may contribute to the dilution of contaminant concentrations in these samples, resulting in lower contamination levels than those dark grey sediments despite their darker appearance.

In contrast to the stormwater ponds, the GP sediments did not show clear or consistent patterns in either the metal ratios or the colour analysis. This difference is likely related to the catchment scale and upstream-downstream position of the facilities. Gully pots are located close to pollutant sources and drain small, highly heterogeneous areas (Wei et al., 2023), typically trapping material dominated by road-derived and urban particles, resulting in a more uniform sediment composition (in texture) even though concentrations can vary widely. By comparison, end-of-pipe stormwater ponds receive runoff from much larger and more mixed catchments, integrating inputs from both natural and anthropogenic sources, which contributes to the larger variations observed in their sediment characteristics. Thus, the use of soil-normalised metal ratios becomes less meaningful for GP, as the sediments consist largely of gravel and road-associated material rather than natural soils. Although several metals (except Cd) showed the highest median concentrations in the dark grey group, these differences were not statistically significant, possibly due to the influence of gravel on both sediment colour and contaminant levels.

3.3 Microscopy

Microscopic examination of the stormwater pond sediments revealed clear differences in particle characteristics between sites. The Örebro samples contained fine, clay-like material, whereas the Växjö samples included larger mineral particles, consistent with their particle size distributions. A range of anthropogenic particles was also identified, including clothing fibres, plastic fragments and metal pieces, particularly in samples from Växjö and Stockholm. Another notable observation was the presence of glass beads in samples from both Stockholm and Östersund, likely originating from reflective materials used in road markings, similar to findings by El-Mufleh et al. (2014). Several samples contained unidentified black particles; however, these could not be conclusively identified as tyre wear or road wear particles. Figure 3 shows a selection of microscopic images.

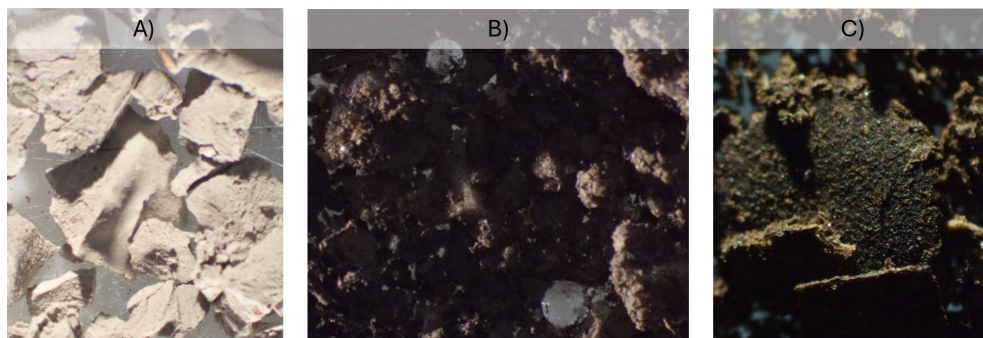


Figure 3: Microscopic images from A) Clay-like sediments in Örebro, B) Glass beads, and C) Unidentified black particles.

This study demonstrates that colour analysis, XRF, and microscopy can provide useful preliminary insights into stormwater sediment contamination, particularly in stormwater ponds where spatial patterns were observed. While these methods cannot replace comprehensive chemical analyses, they offer a practical screening approach for resource-limited municipalities. Future work should refine these proxies and validate their applicability.

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