Intra- and inter-site variability of soil contamination in vegetated roadside embankments – Implications for maintenance operations

Variabilité intra- et inter-sites de la contamination du sol sur les accotements routiers végétalisés – Implications sur les opérations d'entretien

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RÉSUMÉ

Cette étude s'intéresse à la contamination métallique de terres d'accotements routiers (i) en caractérisant la variabilité des concentrations avec la distance de la route et la profondeur, et (ii) en recherchant des variables explicatives des différences entre les sites. Pour ce faire, 40 tronçons de routes ont été sélectionnés et échantillonnés à 5 distances de la route et deux profondeurs. Les teneurs en métaux traces ont été analysées par spectrométrie de fluorescence X. La contamination en cuivre et en zinc se concentre essentiellement en bordure de chaussée, avec des teneurs de 45 à 330 mg/kg pour le cuivre, et 150 à 1000 mg/kg pour Zn. Le plomb présente une distribution plus uniforme sur tout l'accotement avec des niveaux de contamination globalement modérés, conséquence probable de la diminution des sources de Pb avec l'interdiction de l'essence plombée. Pour chaque distance jusqu'à 1,2 m, une corrélation significative est visible entre les concentrations en Zn (ou Cu) et la densité du trafic sur la route adjacente. Pour un trafic donné, le taux de poids lourds tend à accroître la contamination de l'accotement. Ces résultats prometteurs permettent d'envisager une extrapolation à des sites non échantillonnés, afin de mieux appréhender les besoins d'entretien de ces infrastructures et potentiellement d'améliorer les pratiques de maintenance courantes.

ABSTRACT

This study addresses metallic contamination of roadside embankments. It aims to (i) characterize the variability of metal contents with respect to the distance from the road and soil depth, and (ii) evaluate the effect of influencing factors on the inter-site differences. 40 road segments were selected and sampled at 5 distances from the road and 2 soil depths. Analysis of trace metals was performed *via* X-ray fluorescence. Cu and Zn contamination was found to be mainly restricted to the first 30 cm of soil and lied between 45-330 mg/kg and 150-1000 mg/kg, respectively. Pb, however, shows a more uniform distribution over the width of the embankment, with moderate contents which could be interpreted as a consequence of the partial elimination of Pb sources after the ban on leaded gasoline. For every distance from the road up to 1.2 m, Zn (or Cu) contents correlated well with the traffic density on the adjacent road. Moreover, for a given traffic, the percentage of semi-trucks tended towards increasing soil contamination. These promising results may enable the *a priori* estimation of contamination levels on embankments without undertaking soil sampling and analysis; this offers interesting perspectives to better take into account the infrastructures' maintenance needs, and potentially improve upon routine maintenance operations.

KEYWORDS

Metals, Road runoff, Soil contamination, Stormwater management, Traffic, Vegetative filter strips

1 INTRODUCTION

In road environments, stormwater management is generally achieved through a system of filter strips, ditches, detention/infiltration basins, and/or other structural Best Management Practices. It has been widely documented that the infiltration of contaminated runoff into the soil of roadside embankments results in a long-term accumulation of ubiquitous and persistent traffic-related compounds such as trace metals or polycyclic aromatic hydrocarbons (Napier *et al*., 2009; Werkenthin *et al*., 2014). Besides, due to the progressive formation of a humus and sediment layer at the soil surface, the infrastructure has to undergo regular maintenance – mostly consisting of surface soil scraping – so as to preserve its hydraulic functions by ensuring diffuse inflow of road runoff. Hence, the pervasive contamination of soil brings about several questions regarding the specific requirements for the disposal, reuse or treatment of the excavated materials.

Despite a relatively abundant literature about metal contents in roadside soils (Werkenthin *et al*., 2014), it is still difficult to identify pragmatic responses to these concerns. Intra-site variability is rarely characterized at resolutions fine enough to be of operational interest (Tedoldi *et al*., 2017). As to inter-site variability, several factors have been investigated (among which traffic density and composition, road age, vehicular speeds, and vegetative cover) but there is no consensus over their effects and their relative importance. In other words, soil contamination does not appear to be easily predictable. This may be due to the fact that the authors did not account for the spatial variability of concentrations *within* the system itself, thus comparing soil samples with different levels of representativeness. By using a well-designed methodology, Horstmeyer *et al*. (2016) could evidence a trend between Cu, Pb or Zn contents and the annual average daily traffic, in the case of vegetated infiltration swales.

The first objective of the present work is therefore to extend this approach to the case of roadside embankments, using a proper assessment of the site-specific distribution of metals in the surface soil to generate comparable data between sites. In doing so, a second goal is pursued, which consists of identifying accurate descriptors of soil contamination among traffic characteristics and possibly pedological parameters. For that purpose, the French department of *Seine-et-Marne*, in the Paris region, has been retained as a study area, where an improved sampling methodology has been applied to 40 embankments alongside departmental roads with different traffic characteristics.

2 MATERIAL AND METHODS

2.1 Study sites

Seine-et-Marne is a semi-rural district in the Paris Region with an area of ~6000 km^2. It contains around 4000 kilometers of roadways managed by the county council. The 40 study sites were spread across all the department’s area to encompass most of its soil types and environments. They were chosen to guarantee a uniform bivariate distribution of two road factors which were deemed relevant: the annual average daily traffic (AADT) and the percentage of semi-trucks. So as to target the traffic-related sources of contamination, none of the study sites had a metallic guardrail – except two of them which were retained for comparison purposes – nor had them road signs or street lights along the sampled section. The date of the latest maintenance operation was not always known with precision, but it was in any case prior to five years for each embankment.

2.2 Sampling methodology

The sampling methodology was designed to capture the transversal trend of soil concentrations, *i.e.* their distribution with respect to the distance from the road: soil samples were collected at four to five distances depending on the width of each embankment (0, 0.3, 0.7, 1.2, and 1.8-3 m). Mean samples were composited from 6 different locations on a transect parallel to the road and quartered to mitigate the effects of a potential variability at any given distance (Fig. 1). The sampling depths corresponded to the upper 2 cm, and the underlying layer (2-5 cm) whenever the road sub-base was deep enough.

2.3 Sample pre-treatment and analysis

All samples were oven-dried at 40°C, ground with a pestle, then passed through a 2-mm nylon sieve. Elemental analysis was achieved *via* X-ray fluorescence spectrometry (*Thermo Scientific*, portable Niton™ analyzer XL3t). 4 to 6 homogenized subsamples were analyzed independently, thus enabling the repeatability to be checked, then each sample was assigned its average metal contents. Among the analytical range of the apparatus, copper, lead, and zinc, as well as nickel and chromium when quantifiable, were retained as tracers of traffic-derived contamination, because of their well-documented relevance in urban and highway stormwater runoff (Huber *et al*., 2016).

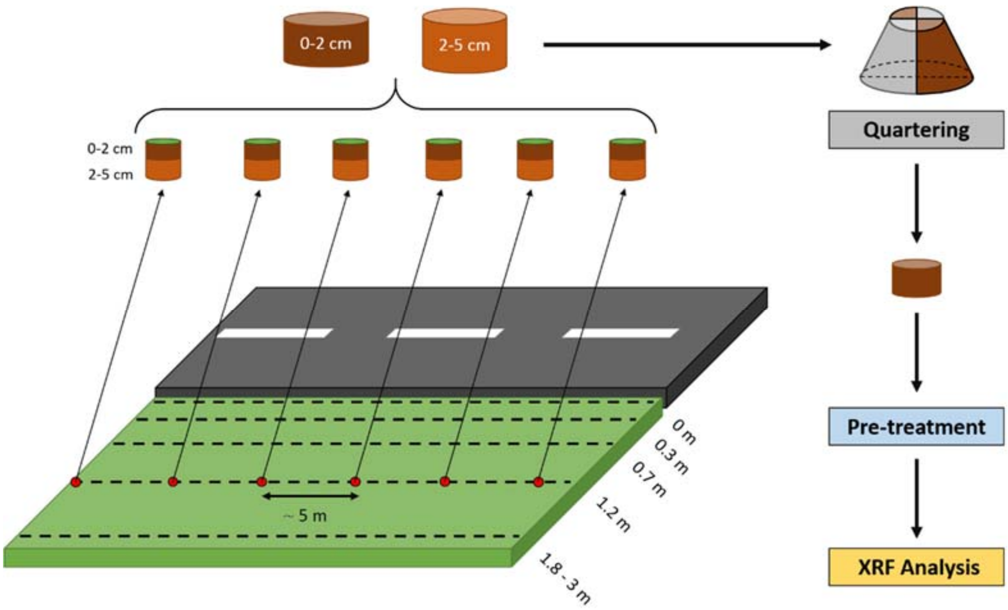

Fig. 1 – Schematic representation of the methodology for soil sampling.

3 RESULTS AND DISCUSSION

Cu, Pb, Zn, and to a lesser extent Cr were consistently above the analyser's limits of quantification and thus were considered for further analysis. Cu and Zn appeared to be strongly correlated (Spearman $\rho = 0.85$). Their typical distribution within each site consisted of a continuous decrease in concentrations with increasing distance from the road, and a slight decrease between the surface sample and the underlying one (Fig. 2), which is consistent with previous assessments (Werkenthin *et al*., 2014). The median ratio between the concentrations found at 0 and 1.2 m was 2:1. These patterns were however not systematically replicated by Pb or Cr (Fig. 3); the relative uniformity of their distribution across the entire width of the embankments, as well as their moderate contents in most sites, might be a consequence of the diminishing sources of these two metals in road environments. As discussed elsewhere, the spatial variability of copper and zinc reflects the time-integrated signature of cumulative water fluxes and sediment deposition at the soil surface: it especially demonstrates that infiltration is limited to a narrow area for most rainfall events, given the prevalence of long-duration, low-intensity events in the Paris region (Tedoldi *et al*., 2017).

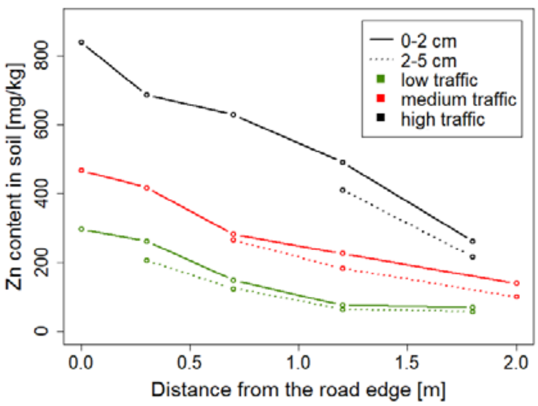

Fig. 2 – Typical distribution of Zn in 3 embankments with contrasting traffic densities.

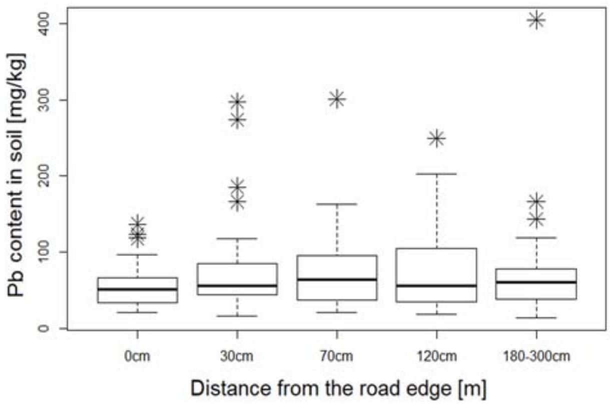

Fig. 3 – Surface Pb contents across all sites, as a function of the distance from the road.

Data from each site was then synthesized into different indicators to be used as a basis for inter-site comparisons. For instance, considering the significant build-up of zinc or copper near the road edge, the mean content in the first 30 cm of each embankment was assumed to constitute a relevant information about the sites' contamination levels. This indicator was plotted against AADT in the case of Zn, with colour gradients representing the percentage of semi-trucks (Fig. 4). An increasing trend was observable over the entire range of traffic, reflecting the effect of increasing emission sources – which in road environments have been shown to be essentially brake and tire wear for Cu and Zn, respectively

(Huber *et al.*, 2016) – on pollutant build-up in roadside soil. Similar trends could also be observed at every distance from the road up to 1.2 m: the slope of the regression line decreased with increasing distance. The vertical dispersion of the data points could be attributed partly to truck traffic, and probably to differences in soil characteristics resulting in variable retention properties.

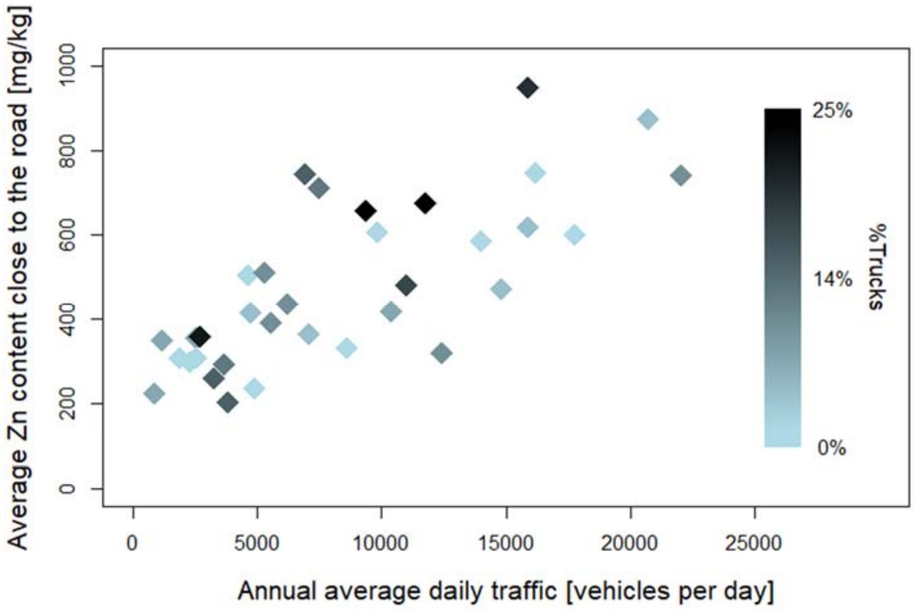

Fig. 4 – Relationship between the mean content of Zn in the first 30 cm of each embankment and the traffic characteristics (AADT on the horizontal axis and %Trucks represented as a colour gradient).

Interestingly, most studies which focused on road runoff did not evidence strong correlations with traffic indicators owing to the significant inter-event variability of metals concentrations (Huber *et al*., 2016). Although stochastic processes seem to govern concentrations in runoff, long-term accumulation in soil acts like an averaging process which mitigates the inter-event variability. This illustrates the interest of targeting the soil medium for such assessments, given its propensity to function as a “passive sampler” of traffic-derived metal fluxes from the road to the embankment.

4 CONCLUSIONS

In the present study, soil contamination in roadside embankments was investigated through an extensive sampling campaign in the Paris area. The results obtained demonstrate: (i) a good reproducibility of the “typical” intra-site distribution of metal contents; and (ii) a clear tendency between Zn and Cu levels in the most contaminated zone of each site and the annual average daily traffic of the nearby road. These results could be achieved thanks to a simplified albeit carefully designed sampling protocol which enables a proper comparison of data with identical representativeness. Further research will focus on the soil characteristics (especially organic matter content) as a possible additional source of variability.

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