Trace metals trapping dynamics in urban stormwater constructed treatment wetlands: Cases study in Strasbourg, Moulins-les-Metz and Leuville-sur-Orge

Dynamique du piégeage des micropolluants métalliques au sein des zones humides artificielles traitant des eaux pluviales urbaines strictes : Etude de cas à Strasbourg, Moulins-lès-Metz et Leuville-sur-Orge

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RÉSUMÉ

Des zones humides artificielles rattachées à des réseaux pluviaux stricts à Strasbourg (Alsace), Moulin-lès-Metz (Lorraine) et Leuville-sur-Orge (Ile-de-France) reçoivent et traitent des eaux de ruissellement issues des bassins versants urbains mais à l'occupation des sols différentes. Constituée d'une mare de sédimentation et d'un filtre planté de roseaux à écoulement vertical, cette filière permet entre autre de piéger les micropolluants métalliques. Le but de cette étude est d'étudier le comportement des micropolluants métalliques (Cd, Cu, Pb et Zn) dans ces ouvrages de traitement. Le piégeage des métaux dans les compartiments sols et plantes du filtre planté a été analysé. L'étude de la spéciation des métaux dans les différentes couches du filtre (dépôt, sable) par extractions séquentielles a de plus permis de déterminer la forme de piégeage et ainsi de mieux comprendre les risques de relargage lors de potentiel changement des conditions physico-chimiques dans le filtre. Des résultats sur la stabilité des métaux dans le filtre ont été obtenus illustrant, (1),un piégeage préférentiel dans les premiers centimètres du filtre (dépôt sédimentaire)et (2) la présence des métaux en quantité négligeable dans les plantes et tout particulièrement leurs racines.

ABSTRACT

Stormwater constructed wetlands (SCW) in Strasbourg (Alsace, France), Moulin-lès-Metz (Lorraine, France), and Leuville-sur-Orge (Ile-de-France, France) receive and treat exclusively runoffs from urban catchments but with different soil uses. Made up of sedimentation ponds and a vertical subsurface flow constructed wetland, the treatment facilities lead to trap several trace metal pollution. Each site belongs to different hydroclimatic areas (modified oceanic, modified continental and semi-continental) and was designed for different purposes (watercourse protection in Strasbourg and in Leuville-sur-Orge, protection of drinking water wells in Moulins-lès-Metz). The aim of this study is to explore trace metals (Cd, Cu, Pb and Zn) behaviours in these SCW. We investigated trace metal trapping by determining concentrations in the systems compartments (filters media and plants). Then trace metal speciation was determined through sequencial extractions of the sediment and filter media. This allowed to determine their forms in soils and to anticipate their behaviour during physical and chemical condition changes. This study permits to obtain first results for the metals stability, to highlight a decrease of the concentrations through the SCW depth (from surficial sediment to clean filter media) and to observe a negligible metal trap in plants (mainly in roots).

KEYWORDS

Constructed wetland, micropollutant, sequential extraction, speciation, trapping

1 INTRODUCTION

In 2000 the European Water Framework Directive [2000/60/CE] gave objectives to improve the global quality of water bodies across Europe. Hence the necessity to reduce all water bodies' pollutions sources and one of these is stormwater runoffs. Stormwater from urban catchment (impervious surfaces) content floating solids, suspended solids, oxydisable matter (COD, BOD_5), nutrients (nitrogen and phosphorus), mineral micropollutants (trace metals), organic micropollutants (hydrocarbons, pesticides) and microorganisms as bacteria (Tassin and Thevenot, 1993). The sources of these pollutants are variable: initial rain water quality, atmosphere crossing, runoff on roofs and roads catchment and in the sewer system (Tassin and Chebbo, 2000).

Among these pollutants, trace metals are identified as the most toxic compounds for the fauna and flora (Guittonny-Philippe et al., 2014).In constructed wetlands, metals are trapped in the filter media or released in water phase depending on hydrological, physical or chemical conditions and their changes. So trace metal behaviour in stormwater constructed wetlands (SCW) is a key point to evaluate the long term efficiency of these treatment facilities.

The present study aimed at exploring behaviours of trace metals such as Cd, Cu, Pb and Zn in three SCWs at the downstream of three urban catchments located in France at Strasbourg (Alsace), Moulin-lès-Metz (Lorraine), and Leuville-sur-Orge (Ile de France). First the trace metal trapping was investigated by determining the total concentrations in the systems compartments (water, soil and plants). Then trace metal speciations were studied in SCWs to determined trace metal forms in filter media, to anticipate their behaviour during potential physical and chemical condition changes and to improve SCWs management.

2 MATERIAL AND METHODS

2.1 Treatment system

Table 1 below presents the three treatment facilities:

Table 1: Strasbourg, Moulin-lès-Metz and Leuville-sur-Orge sites characteristics

Constructed wetland location	Catchment	Constructed wetland characteristics	
		Settling pond	Vertical filter
Strasbourg	2.7ha: residential area	28 m^2	100 m^2
Moulin-lès-Metz	36.5ha: commercial and residential area	215 m^2	2,050 m^2
Leuville-sur-Orge	24ha: residential, commercial area and national road	150 m^2	2,500 m^2

All vertical filters were planted with *Phragmites Australis* and filled with three different filtration layers (top, transition and drainage layers). The pond provides a primary treatment (settling of the heaviest particles and separation of floatables). Then, the SCWs reduce the metallic pollution load thanks to different sorption mechanisms involving metal properties, physico-chemical conditions, filter media characteristics and affinities with different metals, organic matter, water content and other pollutant contents.

2.2 Soils and plant samplings

This study presents the sampling campaign took place in May 2015, about four years after SCWs setting up. The filters were split in two sampling areas according to the plant abundance (low or high). Indeed, in the SCW the plant density is the highest around the feeding device. Hence one sampling area (area 1) presents the biggest and dense *Phragmites australis* while the other one (area 2) presents smallest and scattered *Phragmites australis.* This area is thus not fed during small rain events.. It can be expected that trace metals contents in soil and plant will follow the plant area distribution in the filters for the three SCWs. For each sampling area, the filter media were sampled at three different depths (from top to bottom): accumulated sediments at the surface, sand-sediment mixture (dirty or dark sands) and a deeper sand layer (rather clean sand). From each sampling area, the collected *Phragmites australis* were separated into roots and aerial parts samples. Finally for each area, composite samples from constructed wetlands were made by mixing several sampling of the same type and depth.

2.3 In situ Xray fluorescence (XRF) measurements

For each site in situ metal (Cd, Cu, Pb and Zn) measurements were performed using a portable XRF spectrometer (Niton XL3t). At Strasbourg and Leuville-sur-Orge a systematic sampling grid was determined and a XRF measurement was done at each node on raw material. Concentrations measurements are then considered as qualitative.

2.4 Soils and plant analysis

All soil samplings are conditioned before experiments: they are ground, 2mm sieved and dried at 40°C according to the ISO standard 11-464.

The Tessier sequential extraction (Tessier et al., 1979) is used to determine Cd, Zn, Pb and Cu speciation in soils. By using selective reagents, five specific metal fractions were extracted: the exchangeable, the fraction bounded to carbonates linked with iron and manganese oxides, the fraction bounded to organic matter and residual).

The sequential extractions were controlled by measuring pseudo total trace metals content with aqua regia and mineralization according to the ISO 11-466 procedure. Checking the mass balance by comparing the five extracted fractions with the pseudo total content, differences lower than 35%were accepted.

Plants were digested using HNO3 and heated up at 160 °C during 4 hours. Then the concentration of metals in extracts is measured by ICP-MS.

3 RESULTS AND DISCUSSION

This extended abstract focusses on Strasbourg site. Other sites will be presented and compared in the full presentation.

3.1 Metal trapping

Concerning *Phragmites australis* all metals concentration are higher in roots than in leafy part and they are not more concentrated in the area 1, the most supplied by water one (Table 2), except for Zn. This behaviour is illustrated by XRF measurements; they systematically show a metal concentration decrease from the feeding point towards to the end of the CW. Metals concentration decreases with the depth in the CW (Table 3). Trace metal concentration is about the same in filter and pond sediments. Finally Cd is an exception being only detected in sedimentation pond materials. In conclusion metals are mostly concentrated in roots and in the first centimeters of CW. In terms of trapping it will be important to compute a metal mass balance in order to precise the importance of sediment trapping relative to root perennial trapping.

Table 2: Metals content in *Phragmites australis*

Concentration (mg/kg Dry Wieght)	Cd	Cu	Pb	Zn
Aerial Plant (area 1)	<0.01	1.3	0.01	11.0
Aerial Plant (area 2)	<0.01	1.5	<0.05	8.3
Roots (area 1)	0.02	5.4	0.5	18.0
Roots (area 2)	0.03	2	0.9	10.0

Table 3 : Metals trapping division

Concentration (µg/g)	Cd	Cu	Pb	Zn
Sedimentation pond	0.3	23.9	19.1	81.9
Sediment (area 1)	<0.01	17.0	18.7	86.8
Sediment (area 2)	<0.01	8.4	13.4	66.5
Dirty sand (area 1)	<0.01	2.3	2.4	11.3
Dirty sand (area 2)	<0.01	2.0	2.1	4.7
Clean sand (area 1)	<0.01	2.0	2.3	2.0
Clean sand (area 2)	<0.01	1.9	2.6	1.7

3.2 Metals speciation

Cu, as for Pb, is mainly linked to organic matter fraction in sediment layer and to residual fraction in sand layers (Figure 1). Zn is mainly bound to residual minerals and carbonates in sediment layer, and to organic matter and oxides in sand layers. So Cu and Pb are quite unstable in sediment layer and Zn in sand layers under oxidizing conditions: organic matter can be oxydised leading to a release of Cu, Pb and Zn in infiltrated water (Tessier et al., 1979). Moreover Zn is also sensitive to redox conditions in the sand layers, likely released for low redox values. In sand layers Cu and Pb are stable in the residual fraction. Zn trapping is unstable in sediment and sand layers: the carbonate fraction is sensitive to pH changes.

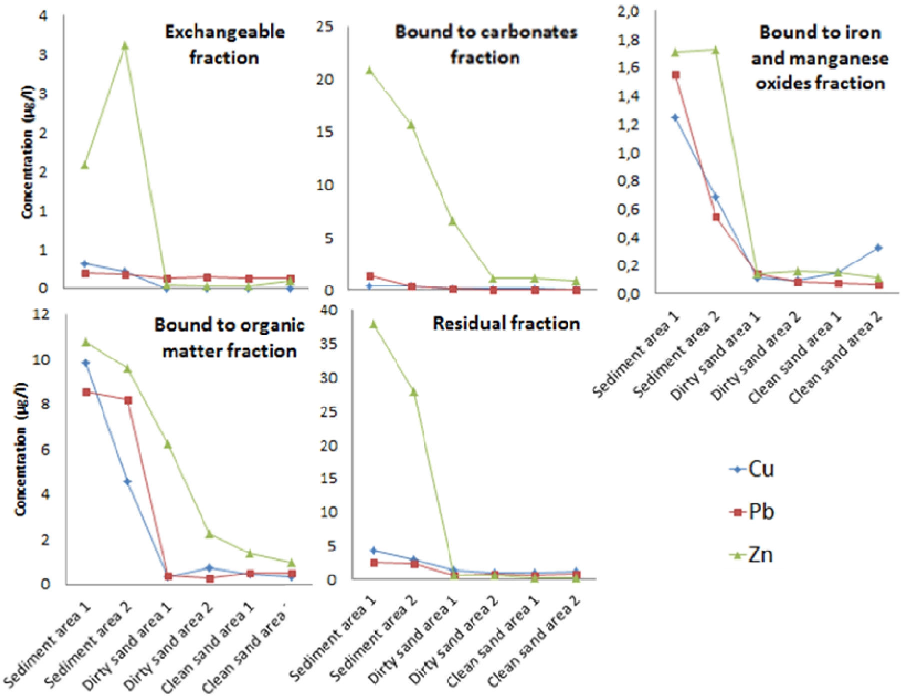

Figure 1: Cu, Pb and Zn soil speciation

3.3 Conclusion

The aim of this study was to determine Cd, Zn, Pb and Cu trapping in different treatment facilities and to evaluate their speciation in soils with a Tessier sequential extraction. In order to do so all the compartments have been studied: pound sediment, *Phragmites australis* aerial part and roots, sediment and sand layers. For all metals there is root enrichment in *Phragmites australis* relative to leafy part. In the filtration media Zn is mostly found in the area 1, the most supplied by water. Finally metals are trapped in the first centimeters of CWs, the sediment deposit. The speciation results show that there is a risk of metal release from sediment to water under oxidizing conditions (for Cu,Pb and Zn),, from sand to water under low redox values for Zn and from sediment and sand to water with pH changes for Zn. So the next step of this work will be to link metal speciation and physico-chemical conditions changes in the CWs.

BIBLIOGRAPHIE

Guittonny-Philippe, A., Masotti, V., Höhener, P., Boudenne, J.-L., Viglione, J., Laffont-Schwob, I., 2014. Constructed wetlands to reduce metal pollution from industrial catchments in aquatic Mediterranean ecosystems: A review to overcome obstacles and suggest potential solutions. Environ. Int. 64, 1–16.

Tassin, B., Chebbo, G., 2000. Qualité des rejets urbains de temps de pluie. Cours ENPC Paris 1–38.

Tassin, B., Thevenot, D., 1993. Rejets urbains par temps de pluie: pollution et nuisances : actes des troisièmes journées du diplôme d'études approfondies - Sciences et techniques de l'environnement - organisées les 14 et 15 mai 1992 `a Paris., Presses de l'Ecole nationale des ponts et chaussées.

Tessier, A., Campbell, P.G.C., Bisson, M., 1979. Sequential extraction procedure for the speciation of particulate trace metals. Anal. Chem. 51, 844–851.