Hydro-sedimentological factors impacting the distribution and abundance of microplastics in fluvial ecosystems

Les facteurs hydro-sédimentologiques impactant la distribution et l'abondance des microplastiques dans les écosystèmes fluviaux

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RÉSUMÉ

La gestion des déchets plastiques est une préoccupation majeure pour le XXIe siècle, avec environ 80 % de la production mondiale annuelle déversée dans l'environnement. Malgré des niveaux de pollution comparables à ceux observés dans les mers et océans, les écosystèmes d'eau douce restent peu étudiés, avec moins de 15 % des publications scientifiques consacrées à ces milieux. Dans ces conditions, les liens entre les variables hydro sédimentaires et la dynamique des microplastiques dans les rivières ont été très peu étudiés. Le but de ce travail est donc d'évaluer comment les échanges hydrologiques à l'interface eau-sédiment affectent la distribution en microplastiques dans les sédiments de rivière. Les concentrations de microplastiques ont été examinées entre des zones caractérisées par des échanges eaux de surface / eaux souterraines (zones d'infiltration et d'exfiltration) et des zones de sédimentation sur le cours inférieur de la rivière d'Ain (France). Les sédiments ont été échantillonnés à 15 emplacements (5 stations pour chaque condition hydro-sédimentaire) à deux profondeurs différentes par pelletage en surface et par pompage à 20 cm de profondeur (méthode Bou-Rouch). Les échantillons de sédiments ont été tamisés avec deux mailles différentes (500-5000 µm et 20-500 µm) pour analyser deux gammes de taille de particules. Cette étude montre que les échanges hydrologiques à l'interface eau-sédiment définissent des zones d'accumulation en microplastiques dans les cours d'eau.

ABSTRACT

Plastic waste management is one of the major challenges of the 21st century with around 80% of the annual worldwide production released into the environment. To date, despite equivalent contamination levels than in marine water bodies, microplastic contamination of freshwater ecosystems remains poorly studied with less than 15% of scientific publications devoted to these ecosystems. In such conditions, hydrological and sedimentary factors controlling microplastic dynamics in streams and rivers have been understudied. Here, we investigated how hydrological exchanges at the water-sediment interface determine the concentrations of microplastics found in riverbed sediment. The concentrations in microplastics were compared between zones with strong surface-groundwater exchanges (strong upwellings or downwellings), and sedimentation zones of the lower Ain River (France). Using a shovel and the Bou-Rouch pumping method, sediments from 15 stations (5 stations per hydro-sedimentary condition) at two different depths (i.e. surface and -20 cm) were sampled. Sediment samples were then sieved with two size meshes (500-5000 µm and 20-500 µm) to analyze large and small microplastic particles. This study showed that hydrological exchanges at the water-sediment determine zones of microplastic accumulation in streams.

KEYWORDS

Freshwater, hydrological exchanges, hyporheic zone, microplastics, sedimentation zones.

1 INTRODUCTION

Fluvial ecosystems are one of the major pathways for plastic waste to enter oceans and seas, carrying 0.47 to 2.75 million tonnes of plastic litter annually (Mani et al., 2019). Similar to natural particles the transport of microplastics in the riverine system largely depends on the properties of the particle (size, shape, density, surface roughness) and the hydrodynamic transport conditions within the water channel. Therefore, the transport of microplastics within the river might not necessarily lead to the oceans directly because some of these particles can be deposited and retained temporarily within riverbed sediments (i.e. particle residence time). Under low flow conditions or water stagnation, microplastics are supposed to settle to the bottom on the riverbed. However, microplastics are re-suspended into the water column during floods. In contrast, mechanisms can be different in hyporheic zone where hydrological exchanges between surface and groundwater occur. In one hand, under downwelling conditions (exchanges from surface water to hyporheic zone), microplastics can be transported through porewater by advective flows and may be trapped in the streambed for long periods. On the other hand, microplastics can be flushed out from hyporheic zone under upwelling conditions (hydrological exchanges from hyporheic sediment to water column) (Drummond et al., 2020; Frei et al., 2019).

Consequently, streambed sediments could act as sinks for microplastics depending on hydrogeomorphological conditions. The present study focuses on the distribution of microplastics under the influence of hydro-sedimentological forces that influence particle deposition and retention in streambed sediments. The concentrations of microplastics in the streambed of Ain River were compared among contrasted hyporheic zone sites (i.e. surface water - groundwater exchanges sites with zones of strong upwellings and zones of strong downwellings) and sedimentation zones (i.e. water stagnant sites). Our hypothesis was that under the effect of the downwelling flows of the surface water, microplastic particles would be more abundant in riverbed sediments than in zones of strong upwelling. Yet, the sedimentation zones could be severely contaminated with microplastics more than the two other zones.

2 METHODOLOGY

2.1 Sample collection

Ten sites from six gravel bars situated along the lower Ain River (large tributary of the Rhône River) were selected to sample sediments from five upwelling zones and five downwelling zones. Alongside these gravel bars, five sites characterized by stagnant water were identified and sampled to obtain sediments from sedimentation zones. From each sampled sites, three sediment sub-samples were collected randomly and mixed to have a representative sample of each collected zone at two depths: surface (using a shovel) and 20 cm below the water-sediment interface (using Bou-Rouch pump). Finally, sediment samples were kept in glass jars and stored in the refrigerator at 4°C for further processing. In addition to microplastics extraction and quantification, particle size distribution of each sediment sample was measured using a sequential sieving and laser diffraction particle size analyser (Malvern 3000 ©) to evaluate which size of particles were trapped in each studied zone (sedimentation, downwelling and upwelling zones).

2.2 Microplastics extraction

Dry samples were then treated by density separation with zinc chloride solution at a density of 1.6–1.7 kg/l to eliminate mineral sandy particles. Following this step, the remaining material (fine organic and clayey particles, and microplastics) was subjected to wet peroxide oxidation (WPO) using Fenton's reagent (solution of hydrogen peroxide with ferrous sulphate) to remove organic matter. Finally, the remaining material from our samples were vacuum filtered on GF/F filters for later microscopic and FTIR spectroscopic analyses (i.e. counting and chemical analysis).

3. RESULTS AND DISCUSSIONS

During the course of the sediment processing (i.e. grain size analysis and plastic extraction), microplastic particles (both fragments and fibers > 1 mm) were detected in some of the treated sediment samples (Figure 1). These observations showed that riverbed sediment could act as a sink for coarse plastic debris.

Particle size distribution from surface sediment samples showed great differences among selected zones (downwelling, upwelling and sedimentation zones, Figure 2). More precisely, downwelling sites were characterized by higher concentrations of fine sediment particles (i.e. 15% of sands-silts-clays - SSC) whereas only 3% SSC were recovered from upwelling sites. Not surprisingly, sedimentation zones were only constituted by fine sediment particles. These differences in SSC among the zones supported our hypothesis that hydro-sedimentological factors determined the accumulation of fine sediments in riverbeds. In such conditions, strong downwelling and sedimentation zones were expected to harbour the highest concentrations of microplastics. The results of the microplastics extraction and quantification from the sediment samples are under progress and will give new insights about the distribution of microplastics in riverbed sediments.

Figure 1: Microplastics observed at different stages of sample processing

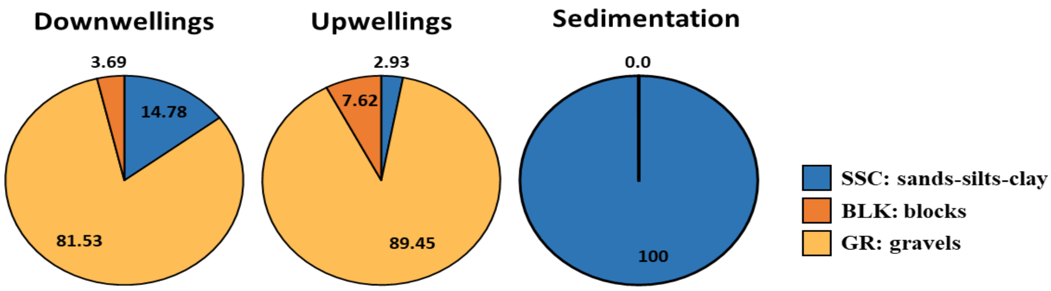

Figure 2: Grain size distribution (%) of sediments sampled from the downwelling and upwelling sites

4. CONCLUSION

Our results showed that riverbed sediments could act as temporal sinks for fine sediments and associated microplastics. Furthermore, hydrological exchanges at the water-sediment interface are key factors determining the retention and immobilization of plastic particles in riverbed. However, further experiments in more contrasted sedimentological conditions (e.g., considering sandy rivers) are needed to expand our knowledge on hydro-geomorphological conditions and microplastics contamination in river sediments.

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