Assessing microplastic transport pathways and potential sources along gravel-bed rivers: Focus on the Ain River

Évaluer le transport et les sources potentielles de microplastiques le long des rivières à charge grossière : Zoom sur la rivière d'Ain

DENDIEVEL André-Marie[1], WAZNE Mohammad[1], VALLIER Manon[1], MERMILLOD-BLONDIN Florian[1], MOURIER Brice[1], PIEGAY Hervé[2], WINIARSKI Thierry[1], KRAUSE Stephan[3], SIMON Laurent[1]

1) Univ Lyon, Université Claude Bernard Lyon 1, CNRS, ENTPE, UMR 5023 LEHNA, 69622 Villeurbanne, France

2) Univ Lyon, ENS de Lyon, CNRS, UMR 5600 EVS, 69362 Lyon Cedex, France

3) School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

RÉSUMÉ

La pollution par les microplastiques (MPs) est devenue une préoccupation majeure pour les rivières et leurs sédiments. En raison de l'hétérogénéité et de la complexité des transferts dans les corridors fluviaux, l'identification des distributions de MPs (concentrations et types) à l'interface sédiment-eau et leur impact sur les écosystèmes associés est à un défi majeur à relever. Dans le cadre du projet Aquaplast, nous étudions les mécanismes de transport et d'accumulation des MPs le long des rivières à charge grossière comme la rivière d'Ain (France). En effet, (i) son bassin-versant comprend des industries plastique, (ii) est influencée par une diversité d'activités urbaines, rurales et loisirs aquatiques, (iii) et présente plusieurs barrages pouvant potentiellement piéger les MPs. L'occupation du sol et la répartition des usines de plastique ont été analysées à l'aide d'un SIG afin d'identifier les sources potentielles de MPs dans le bassin versant. Sur le terrain, quatorze sites clés ont été échantillonnés à -20cm sous l'interface eau-sédiment (en amont et en aval des barrages ou des industries de plasturgie) La granulométrie des sédiments, la température du cours d'eau, la conductivité, les hauteurs piézométriques et les concentrations en MPs ont été mesurées sur chaque site pour décrire les conditions hydro-sédimentaires responsables du transport et du dépôt des MPs. Ce travail a démontré l'efficacité du piégeage des barres alluviales grossières et analyse les voies de transport des MPs le long du continuum et l'effet de l'occupation des sols. L'analyse des relations entre la distribution des sources potentielles de MPs et l'accumulation spatiale des MPs vise à mettre en évidence les hotspots de contamination MPs le long des cours d'eau à charge grossière.

MOTS-CLES

Barres graveleuses, zone hyporéhique, occupation du sol, rivière aménagée, microplastiques

ABSTRACT

Microplastic (MP) pollution has become a key concern in rivers and streambed sediments in recent years. Due to the heterogeneity and complexity of particle transfer in river corridors, the identification of MP distributions (concentrations and types) at the sediment-water interface and the impact of such contamination on the related ecosystem is a major challenge. Within the framework of the Aquaplast Project, we investigate transport and accumulation mechanisms of MP along gravel-bed rivers. We focus on a challenging case: the Ain River (France) because (i) its catchment area includes major plastic industries, (ii) it is influenced by a diversity of urban, rural and water recreation activities, (iii) and it is equipped with several dams potentially trapping MPs. The land-use and the distribution of plastic factories were analysed using GIS in order to identify potential MP sources in the catchment area. In the field, fourteen key sites were sampled at -20cm under the water-sediment interface (upstream and downstream of dams and plastic factories). Sediment grain size, stream temperature, conductivity, piezometric heads and MPs concentrations were measured at each site in order to describe the hydro-sedimentological conditions influencing MP transport and deposition. This work

underlined the trapping efficiency of coarse alluvial bars, transport pathways of MPs along the continuum and the effect of land-use on their delivery downstream. The relationships between the distribution of potential MPs sources and the spatial patterns of MP accumulation in streambed sediments would permit to highlight hotspots of riverine MP contamination.

KEY WORDS

Gravel bars, Hyporheic zone, Land-use, Managed river, Microplastics

1 INTRODUCTION

Since the advent of plastics, their production and uses have continued to grow exponentially and to diversify. Plastics are found in all environmental compartments on Earth, from the atmosphere to marine and freshwater systems. Rivers play a major role in the transport and storage of plastics between continental plastic sources and the oceans (Krause et al., 2021). Indeed, they receive plastic waste by direct release from urban and industrial areas (wastewaters, sludge, runoff, landfills), by degradation or primary plastics or sludge spreading in agricultural areas or by atmospheric fallout. Thus, plastics are found in different sizes, shapes and polymer composition in the environment.

Microplastics (MPs; 5 mm to 1 µm) are commonly invisible to the naked eye, especially when mixed with sediments. According to the current state of knowledge, the highest MP concentrations in water and sediment are due to MP particles ranging from 2 mm to 50 µm (Kooi & Koelmans, 2019). Characterising their pathways in freshwater environments constitutes an important challenge as they can be transported, deposited, or reworked along the watercourse. With respect to these processes, the study of the MPs dispersion in the hyporheic zone of rivers (HZ, zone of exchanges between surface water and groundwater) can be considered as a key mechanism for MPs transport in rivers. Particles transfers between water column and HZ can happen at various scales, depending on the direction of flow between surface water and groundwater, on the sediment porosity and composition. Thus, downwelling sites where surface water enters into the HZ can be studied as suitable environments for MPs accumulation (Frei et al., 2019).

In order to better understand the distribution of MPs in rivers, the present work examined the links between the plastic industry distribution in the watershed and the concentration and composition of MPs in downwelling zones along a gravel-bed river (e.g. the Ain River continuum). Our specific objectives were (1) to analyse the distribution of activities that may be MPs sources within the watershed and (2) to characterise MP distribution in HZ of mobile gravel bars along the river.

2 MATERIAL AND METHODS

2.1 The Ain River continuum: geomorphological and land-use insights

The Ain River is one of the main tributaries of the Rhône River, upstream of the city of Lyon (France). It is meandering river with a coarse bed load (D50 = 26-15 mm), flowing about 1500 m^3 of sediment annually. The Ain River continuum comprises, in the downstream direction, rural areas (Upper Ain River), urban-industrial stretches and dam reservoirs (Middle Ain River), farming and water recreation areas (Lower Ain River). The Middle Ain River is very critical because the area of Oyonnax (located on the Lange-Oignin tributary) is called the “Plastic Valley” and is historically known as one of the most important plastic production area in France.

2.2 GIS approach

A Geographical Information System (GIS) approach by using QGIS was performed at the catchment area scale in order to analyse the distribution of plastic factories. A database was compiled based on corporate directories, historical mentions (extracted from BASIAS), and on street views.

2.3 Sampling plan

Based on the measurement of the stream temperature, conductivity, and piezometric heads, 14 downwelling sites were sampled from March to June 2021. They were located all along the Ain River continuum, with a special focus on the Middle Ain River and its “Plastics Valley” (7 samples). Sediment samples were obtained at -20 cm deep in mobile gravel bars. At each site, three sediment samples were collected using the Bou-Rouch method (manual pumping). These samples were mixed to obtain a 60g composite sample of fine sediments (<3 mm) representative of each sampled site. At each site, bulk sediment samples (ca. 5 kg) were also obtained by using a shovel and a stainless steel 100 µm mesh sieve in order to measure the overall grain size at the sampling location. Then, the sediment samples were stored at 4°C before analysis.

2.4 Grain size and Microplastic analysis

All sediment samples were dried at 55°C during 1 week. To assess the overall grain size distribution, the bulk samples were manually sieved, while the fine sediments were proceeded by laser diffraction.

For MP extraction, the fine sediment fraction (<3 mm) was immersed for 24h in a ZnCl solution (density: 1.6–1.7 kg/l) to separate heavy inorganic materials from lighter particles. The floating material was sieved. Then, it was digested for 24h by using hydrogen peroxide (H_2O_2) and Fenton's reagent to remove the organic matter. The remaining material was filtered and placed on alumina filters. The counting and quality analysis was achieved by using a FT-IR device.

3 FIRST RESULTS AND DISCUSSION

3.1 Plastic factories distribution

More than 550 factories involved in the plastic sector have been identified in the study area (Fig. 1). It includes moulding, transformation and manufacture of finished products, as well as compounders. They are located at two main centres: 65% along the Lange-Oignin River (L-O Centre; Middle Ain River) and 26% along the Bienne River (Upper Ain River). The other plants are located in the lower part of the Ain Valley (9%). We assumed that the distribution of MPs along the river increases from in relation to the distribution of plastic compagnies.

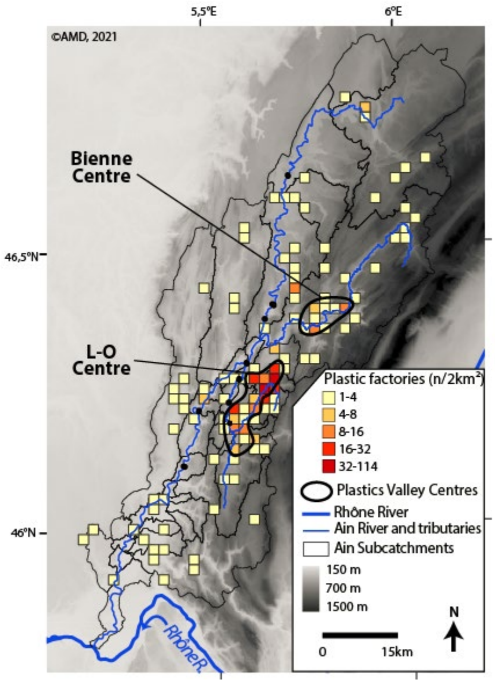

Fig. 1. Plastic factories density on the Ain River watershed.

3.2 Grain-size and microplastics in the sediments of downwelling areas

Despite the overall importance of pebbles and gravels, the grain size analysis showed that the sediment samples from the Bienne and the Lange-Oignin Rivers are richer in SSC (sands, silts and clays) than the Ain River itself (19%, 6% and 2%, respectively). As MPs accumulate preferentially in fine sediments, we expect higher MP concentration in sediments from Bienne and Lange-Oignin Rivers (Middle Ain Valley).

The MP analysis (number, area, types) is ongoing. Methodological tests performed in laboratory with samples spiked with different plastic polymers showed that the analytical protocol permitted to recover around 50% of MPs numbers initially added to sediments and 87% of the area initially covered by MPs. Preliminary analyses indicated that MP particles (size > 0.5 mm) were detected in several samples, which is promising as they validate the presence of MPs in the gravel bars along the river.

4 CONCLUSION

The Ain River continuum appears as a relevant theatre to analyse the MP dispersion in complex gravel-bed rivers. Based on the grain size distribution of particles and on land-use results, an increase in MPs is expected in the Middle Ain River (Bienne and Lange-Oignin tributaries). Downstream, the presence of dams should act as fine sediment traps, limiting the MPs contamination of the Lower Ain River. These assumptions will be further exanimated during the next steps of this work.

REFERENCES

Frei, S., Piehl, S., Gilfedder, B. S., Löder, M. G. J., Krutzke, J., Wilhelm, L. and Laforsch, C. (2019). Occurence of microplastics in the hyporheic zone of rivers. *Scientific Reports*, 9(1), 15256.

Kooi, M., & Koelmans, A. A. (2019). Simplifying Microplastic via Continuous Probability Distributions for Size, Shape, and Density. Environm*ental Science & Technology Letters*, 6(9), 551–557.

Krause, S., Baranov, V., Nel, H. A., Drummond, J. D., Kukkola, A., Hoellein, T., Sambrook Smith, G. H., Lewandowski, J., Bonet, B., Packman, A. I., Sadler, J., Inshyna, V., Allen, S., Allen, D., Simon, L., Mermillod-Blondin, F. and Lynch, I. (2021). Gathering at the top? Environmental controls of microplastic uptake and biomagnification in freshwater food webs. *Environmental Pollution*, 268, 115750.