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Permeable pavements for microplastic pollution control: a laboratory analysis under mediterranean rainfall conditions

Chaussées perméables pour le contrôle de la pollution microplastique: une analyse en laboratoire dans des conditions pluviométriques méditerranéennes

E. García-Haba^{1a}, C. Hernández-Crespo^{1b}, M. Martín^{1c}, A. Benito-Kaesbach^{2,3a}, C. Sanz-Lazaro^{2,3b} & I. Andrés-Doménech^{1d}

¹Instituto Universitario de Ingeniería del Agua y Medio Ambiente – Universitat Politècnica de València, Camí de Vera s/n, 46022 València, Spain; ^aedgarha@iiaama.upv.es; ^bcarhercr@upvnet.upv.es; ^cmmartin@hma.upv.es; ^digando@hma.upv.es

²Department of Ecology, University of Alicante, PO Box 99, E-03080 Alicante, Spain.

³ Multidisciplinary Institute for Environmental Studies (MIES), Universidad de Alicante, P.O. Box 99, E-03080 Alicante, Spain. ; ^aalba.benito@ua.es; ^bcarsanz@ua.es

RÉSUMÉ

Le ruissellement des eaux pluviales lave les surfaces urbaines et entraîne les microplastiques vers les plans d'eau récepteurs. L'impact négatif causé par ce polluant dans l'environnement, souligne la nécessité de le contrôler. L'utilisation potentielle des Systèmes de Drainage Urbain Durables, et des chaussées perméables en particulier, parvient à réduire considérablement les particules en suspension transportées par le ruissellement. L'étude vise à étudier l'efficacité des chaussées perméables à la rétention des microplastiques. La réponse d'une chaussée perméable est testée sous un régime pluviométrique moyen à Valence (Espagne). Les résultats montrent une réduction significative du nombre de microplastiques infiltrés à travers la chaussée perméable. Les fragments de polypropylène étaient les particules les plus retenues. Bien qu'il soit encore nécessaire d'améliorer l'efficacité de la rétention des fibres, la mise en place de chaussées perméables en milieu urbain peut contribuer à réduire la présence de microplastiques dans les déversements d'eaux pluviales.

ABSTRACT

Stormwater runoff washes off urban surfaces and drives microplastics to receiving water bodies. The negative impact caused by this pollutant in the environment, raises the need to control it. The potential use of Sustainable Urban Drainage Systems, and permeable pavements in particular, manage to significantly reduce suspended particles carried by runoff. The study aims to investigate how effective are permeable pavements at microplastic retention. The response of a permeable pavement was tested under the average rainfall regime of Valencia (Spain). The results showed a significant reduction in the number of infiltrated microplastics through the permeable pavement (94%). Polypropylene fragments were the most retained particles. Although it is still necessary to improve fibre retention efficiency, the implementation of permeable pavements in the urban environment may help to reduce microplastic content in stormwater runoff discharges.

KEYWORDS

Microplastics, permeable pavements, pollution control, Sustainable Urban Drainage Systems.

1 INTRODUCTION

Microplastics (MPs) are, by definition, plastic particles whose longest dimension is below 5 mm (Malankowska et al., 2021). This pollutant contributes significantly to the deterioration of natural

resources and wildlife (Grbić et al., 2020; Müller et al., 2020). In wet weather, stormwater runoff conveys important loads of contaminants, reaching water bodies without previous treatment (Piñon-Colin et al., 2020). Engineered nature-based solutions such as sustainable urban drainage systems (SUDS) offer stormwater management, providing water quality treatment among other benefits (Andrés-Doménech et al., 2021). Permeable pavements are a particular SUDS solution, widely used within the urban environment. This technique is presented to effectively trap solid particles and hence MPs (Grbić et al., 2020; Hernández-Crespo et al. (2019) and Fernández-Gonzalvo et al. 2021). In this study, MPs retention capacity of permeable interlocking concrete pavement (PICP) was tested at laboratory scale, under mediterranean rainfall conditions.

2 MATERIAL AND METHODS

The experimental setup consists of a permeable pavement infiltrometer (PPI). From the top to the bottom, the pavement structure is comprised of interlocking concrete pavement (FIT-BLOCK by QUADRO); 5 cm of fine gravel (2-4 mm size); geotextile, 25 cm of coarse gravel (25-40 mm size), and geotextile. The interlocking separation is filled with fine gravel (3-6 mm size). A rainfall simulator was set, which was composed of a grid of drip irrigation pipes, a water storage tank, and two peristaltic pumps (LLG-uniPERISTALTICPUMP 3). A complete description of the experimental device can be found in Fernández-Gonzalvo et al. (2021).

Progressive pollution build-up was simulated applying real sediment of dust and dirt on the PPI surface. The sediment was collected under dry conditions using a mechanical sweeper on paved roads at Universitat Politècnica de València, and its deposition rate on the pavement was 5 g/m²/d, according to Hernández-Crespo et al. (2019). Simplified rainfall inputs aimed at reproducing the average rainfall regime in València (Spain), in terms of rainfall volume, storm duration and inter-event periods. As demonstrated in Andrés-Doménech et al. (2010), average rainfall volume is 16 mm and average storm duration 30 min duration (32 mm/h). These synthetic rainfall conditions were reproduced every two weeks for a 2-year period. Deionized water was used to simulate rainwater.

Solid samples (real sediment) and water samples (infiltrated water) were analysed for microplastic identification. Due to high concentration of organic matter in solid samples, a sequential digestion process was applied using H₂SO₄ 1:1 H₂O₂ (Hernández-Arenas et al., 2021) and H₂O₂ with Fe²⁺ as a catalyst (Hurley et al., 2018). In order to separate plastic particles from the solid matrix, a density method was developed using a saturated solution of deionized water and NaCl, with a concentration of 322 g/L (Bellasi et al., 2021). Then, samples from sediment and infiltrated water were filtered through 1.2 µm fiberglass filters. Microplastics were visually identified using stereomicroscope (MOTIC SMZ 143 N2GG) and Raman spectroscopy.

3 RESULTS AND DISCUSSION

After the 2-year testing period, a total mass of 912.5 g of sediment was deposited on the PPI surface, and a total volume of 59.81 L of water was infiltrated through the PPI. The characterisation study of the real sediment showed a concentration of 4.76 items/g, which supposes an accumulation of 4345.32 items. Identified polymers were polypropylene (PP) (71%), polyvinyl alcohol (PVOH) (10%), polyester-epoxy (7%), polyvinyl chloride (PVC) (5%), PP+cellulose (3%), polyethylene terephthalate (PET) (2%), polymethylstyrene (1%) and PVOH+cellulose (1%). According to shape, fragments were the most common (91%), followed by fibres (8%) and films (1%). It can be noticed that the most common polymer and shape found in the sediment used in this study, coincide with other sediments studied in Mbachu et al. (2022), Ziajahromi et al. (2020), Liu et al. (2019), Olesen et al. (2020) and Townsend et al. (2019).



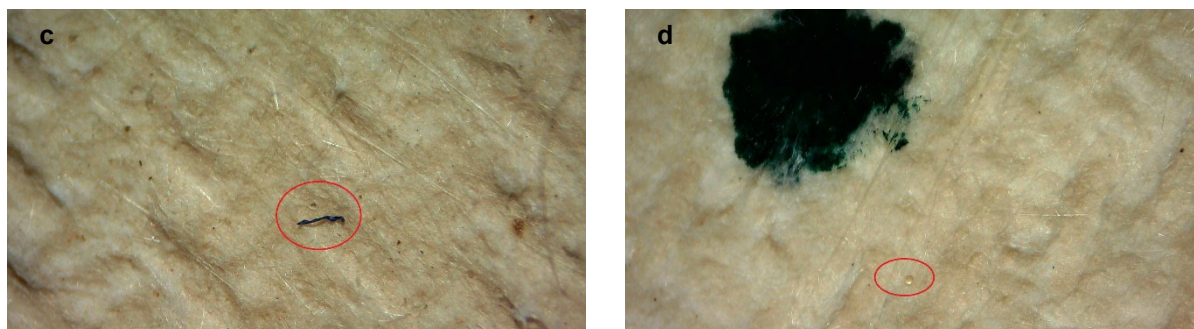


Figure 1. Examples of PP and polyester-epoxy fragments (a) and PP+cellulose film (b) found in the sediment matrix ; and examples of PP fibre (c) and acrylonitrile butadiene styrene (ABS) pellet (d) found in the infiltrated water samples.

In the infiltrated water, microplastic concentration was estimated to be 4.202 items/L, which means 251.32 microplastics released from the PPI. Particles of PP represented the 15% of the total, PVC+PP (13%), whereas ABS, PVOH, PET, polyester-epoxy, PVC, polymethylstyrene, nylon+acrylonitrile+polyester, PET+nylon+polyurethane, PP+PET+nylon, and polyester+PVC were in the same proportion (7.3%). Looking at identified shapes, they were fibers (55%), fragments (37%) and pellets (8%). The results represented in Figure 2 show an important reduction (94%) in the number of microplastic items between the sediment (INPUT) and the infiltrated water (OUTPUT). Assuming total suspended solids (TSS) as a potential indicator of MP pollution due to its strong correlation (Wang et al. 2020), this result is in the same order of magnitude as those obtained by Kamali et al. (2017), between 72% and 100%, and Hernández-Crespo et al. (2019) and Fernández-Gonzalvo et al. (2021), who demonstrated TSS retention efficiencies up to 99% considering high pollution build up and intense rainfall conditions. Minor presence of fragments and films in OUTPUT, in comparison with INPUT, suggests that permeable pavements hold high retention capacity of these shapes. Nevertheless, the proportion of fibers is major in OUTPUT than in INPUT, which is in the same line as in other case studies regarding SUDS for MP retention (Smyth et al. 2021 and Werbowski et al. 2021). This fact indicates that fibres are easily dragged by water across granular and geotextile layers.

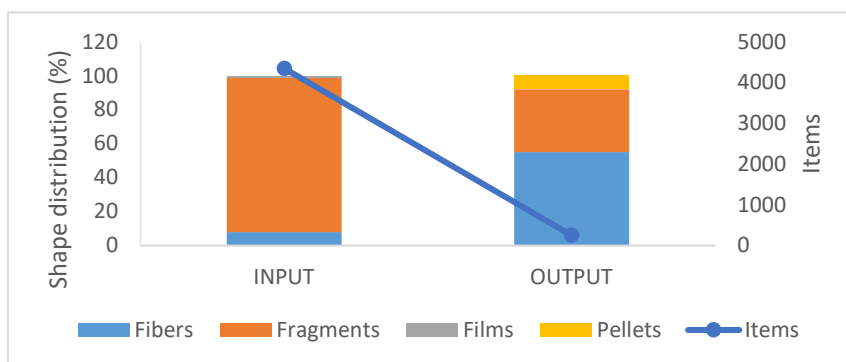


Figure 2. Microplastic shape distribution and total microplastic items found in the deposited sediment (INLET) and in the infiltrated water (OUTLET).

4 CONCLUSION

From the preliminary results of this study, it can be concluded that permeable pavements play a significant role as microplastic retention devices. These permeable structures allow retention of those particles which shape and dimension are prone to be trapped in the surface pavement and underlying layers. In order to improve the effectiveness of permeable pavements, future works should focus on the retention of fibers that scape from the system, considering a better design and the incorporation of new materials with greater retention capacity.

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