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Experimental study on transport and retention dynamics of macroplastics in gully pots

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Abstract

Plastic wastes sourced from urban areas can be retained and transported by urban drainage systems. However, comprehensive research on the transport of plastics in these systems is still required. This study examines the efficiency of gully pots in trapping macroplastics during rainfall events of different intensity, focusing on the influence of flow conditions, plastic types and the presence of sediments. Using a 1:1 scale gully pot model, with water flow ranging from 0.2 to 2.0 l/s we measured the transport and retention of bottles, caps, cigarette filters, and snack wrappings. The results revealed that high discharges significantly reduce plastic removal efficiency –i.e., less plastics remain trapped in the gully pot—, while sediments accelerate plastic transport, especially at high discharges. The study highlights the role of urban drainage systems to mitigate plastic pollution in aquatic environments.

Highlights

- Gully pots retain PETE, cigarette filters, and multi-layer plastics, except during extreme rainfall.
- HDPE plastics transport during low to moderate rainfall, remaining buoyant until later events.
- Regular gully pot cleaning reduces plastic transport during extreme rainfall events.

Introduction

Plastic pollution in aquatic ecosystems is a growing environmental concern, with significant research focusing on its impact in riverine systems before reaching the ocean (Van Emmerik et al. 2020, Waldschlager et al. 2022). Urban areas are the primary source of plastic pollution in rivers (Tasseron et al. 2023), where urban drainage systems play a crucial role in managing stormwater and wastewater. These systems not only protect urban environments from floods but also intercept pollutants to prevent downstream clogging and reduce treatment plant overloads. For instance, sediment traps of gully pots capture various solids (Rietveld et al. 2021), including plastics, but comprehensive research on the transport of plastics in these systems is still lacking.

This research experimentally quantified the efficiency of gully pots in trapping macroplastics during rainfall events of different intensities. The study focused on the influence of flow conditions on the retention and transport of macroplastics within gully pots, disclosing specific discharge thresholds that control transport dynamics. Additionally, the study assessed the impact of different types and quantities of plastics on the overall efficiency of gully pots in removing macroplastics. Finally, the study also explored how sediments in gully pots influence the retention capacity of macroplastics under steady flow conditions.

Methodology

Experimental setup

A 1:1 scaled model gully pot located in the Hydro Hall facilities at Deltares (Delft, the Netherlands) was used to perform the experimental campaign. The gully pot model was made of PMMA (polymethyl methacrylate), and the dimensions were $35 \times 35 \times 101 \text{ cm}^3$. In addition, it had a grated lateral inflow, and a flow outlet opening located 39 cm from the bottom. The gully pot model was connected to a PVC-pipe system, which included an electromagnetic flow meter and a potential-integral (PI) control valve and was operated in a closed loop by pumping water from a 550 L water tank to the gully pot inlet. Additionally, a camera (GoPro HERO9 Black) was used to complementarily record the transport and retention of plastics in the gully pot model and a temperature sensor (DS18B20) was installed in the water tank to monitor water temperature during the experiments. Figure 1 summarizes the experimental setup.

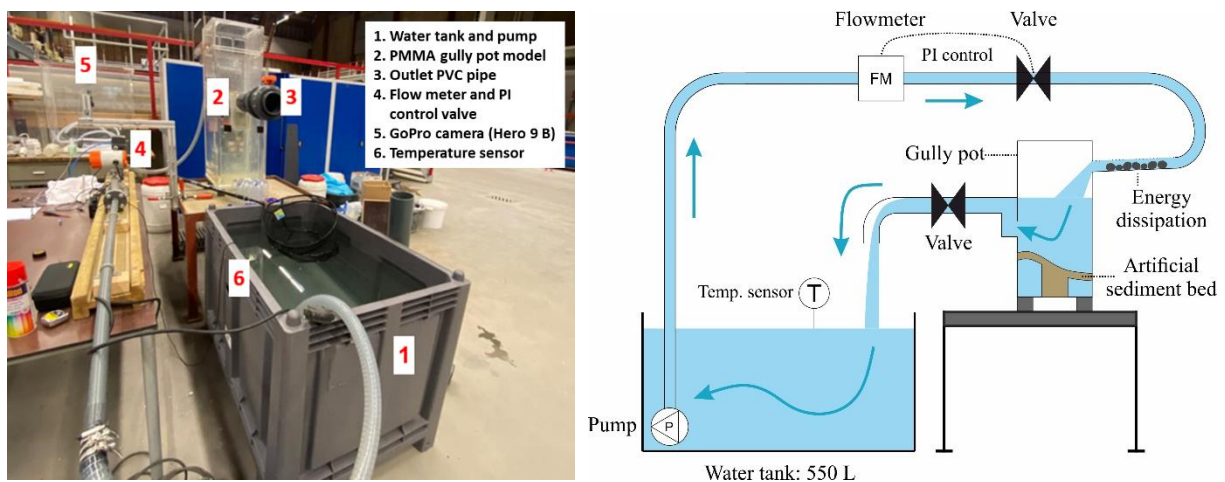


Figure 1. Photo (left) and scheme (right) of the experimental setup.

Experimental procedure

The lab-scale experiments simulated the retention and transport of macroplastics in gully pots, specifically focusing on water bottles (PETE), bottle caps (HDPE), cigarette filters (cellulose acetate), and snack wrappings (multi-layered). First, flow conditions were established using the PI control system, testing both constant and unsteady flow conditions ranging from 0.2 to 2.0 L/s, which corresponds with increasing runoff conditions in the street. Maximum flow rate corresponded to an extreme rainfall event and was calculated by considering a rainfall intensity of 48.6 mm/hr, a catchment area of 220 m², a runoff coefficient of 0.9 for paved roads, and a clogging factor of 25%. Likewise, samples were then introduced into the gully pot model through the inlet. The time required for a plastic particle to travel from the inlet to the outlet was recorded if the particle was transported within the set run timeframe (180 s); otherwise, the particle was considered non-transported. In parallel to these tests, 15 to 35 settling and rising velocity measurements per plastic sample were also performed.

The experiments consisted of a series of runs, varying from 10 to 200, where each run measured the transport of a plastic sample. For instance, an experiment comprising 75 runs indicated that 75 plastic samples were studied. A total of 27 experiments were carried out because of the combination of four types of macro plastics, flow conditions (0.2 – 2.0 L/s), and the presence of a sediment bed layer. The macroplastic selection was based on the literature review and local observations in four urban catchments in Delft (the Netherlands), while the flow range was designed to reproduce low and high intensity rainfall events in an urban catchment of 220 m². To account for sediment bed effects, the gully pot model was also set with and without an artificial sediment bed, whose morphology reproduced actual bed forms in accumulation experiments with sand (Rietveld et al., 2020). Further details of the methodology can be found in Khaled (2023).

Results and discussion

Settling and rising velocity measurements

Regarding settling and rising velocity measurements, Figure 2 illustrates the violin-shape distribution of velocities, with full bottles showing the highest settling velocity, while empty bottles showed the highest rising velocity. In addition, caps and multi-layer plastics showed a predominance of rising velocities, while cigarette filters tended to settle. In the case of multi-layer plastics, there appears to be a bimodality in the rising velocities, which shows similarities to the findings of Valero et al. (2024). The settling or rising velocity, as well as the shape and density of the plastic sample, are key parameters to account for drag forces to understand and predict plastic retention and transport dynamics in aquatic systems.

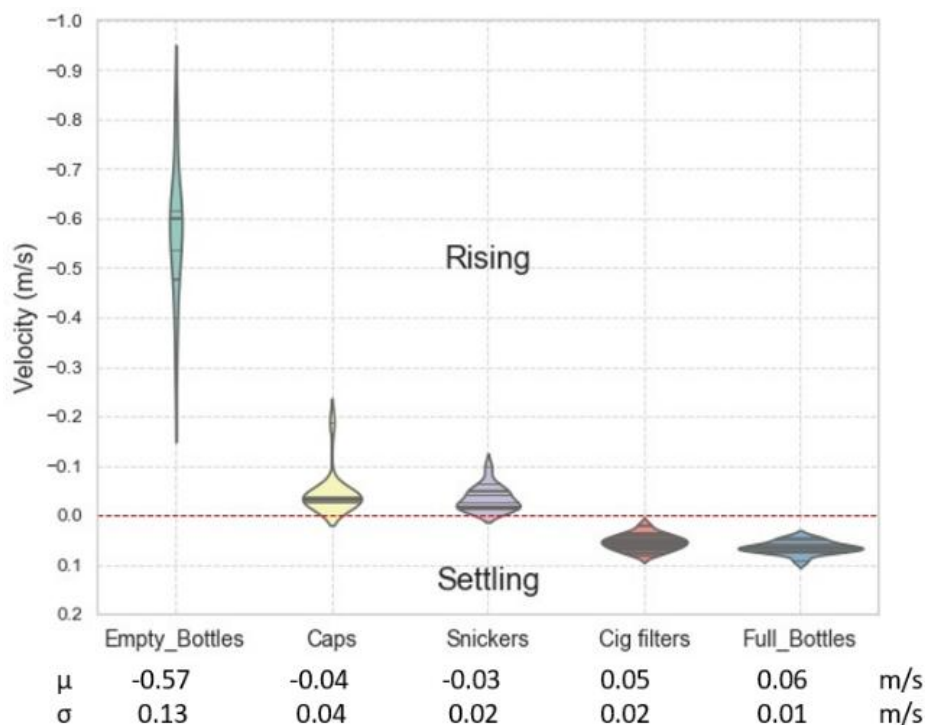


Figure 2. Comparison of settling and rising velocities for different plastic types. μ and σ represent the mean and standard deviation of the rising and settling velocities, respectively. Source: Khaled (2023).

Transport time of macroplastics

A survival analysis using the Kaplan-Meier method was used to compare the transport times of macro plastics under several experimental conditions. The analysis focused on different plastic types, the presence or absence of sediment beds, and steady versus unsteady flow conditions. Figure 3 revealed significant differences in plastic transport durations, with high discharge rates significantly reducing

the removal efficiency of plastics. It was also found that low discharges were insufficient to transport certain macroplastics, such as cigarette filters, snack wrappings, and bottles (PETE). In addition, medium discharges could transport most plastics except bottles, while high discharges showed varying removal efficiencies. We also found that bottles were first slowly, and naturally, filled with water before they would be transported. The change in its transport properties is apparent from Figure 2, where bottles can even reach a null settling velocity in the process of getting filled with water, which would contribute greatly to their transport by the flow. Regarding the presence of sediments, it was found that the artificial sediment bed accelerated plastic transport, especially at high discharges, reducing the transport time of plastics by almost 50%.

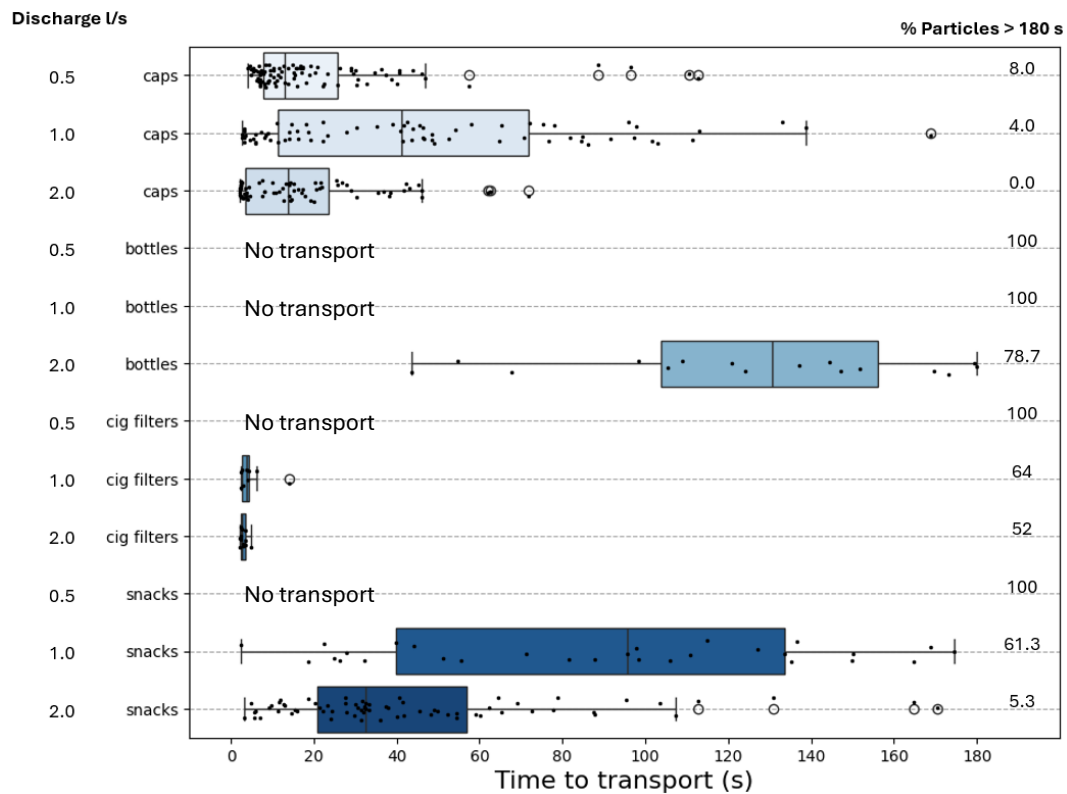


Figure 3. Box plots visualizing the transport time of different types of macro plastics. Data source: Khaled (2023).

Conclusions and future work

Gully pots are effective in retaining certain macroplastics like PETE, cigarette filters, and multi-layer plastics, except during extreme rainfall events. HDPE plastics, however, are more likely to be transported during low to moderate rainfall, remaining buoyant until subsequent events. The presence of sediments in gully pots can accelerate plastic transport during heavy rainfall, highlighting the importance of regular cleaning to reduce plastic pollution. Future work will focus on refining existing models to accurately describe the removal efficiencies of various plastics due to their different densities and geometries.

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