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Sampling Strategies of Microplastic in Stormwater Runoff from Separate Drainage Systems

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Abstract

The occurrence of microplastic in terrestrial and water environments can be traced back to anthropogenic activities. Urban drainage systems play a role in transporting microplastic from urban sources into receiving waters or soils. The analysis (including sampling, sample preparation and detection) of microplastic are very complex and time-intensive, and sampling alone is the main contributor to uncertainty in the process. However, the lack of representative and comparable sampling strategies complicates the efforts to quantify emitted loads and to identify sources and pathways. Therefore, strategies for sampling microplastic in different wastewater compartments were developed and tested. The ongoing phase, however, focuses on sampling stormwater runoff in separate sewer systems. A new autonomous sampling concept for stormwater was designed and implemented to capture large sample volumes. The sample volume plays an important role with respect to the representativeness. Samples are then prepared, both in situ and in laboratory to produce five size fractions (1000, 500, 100, 50, 5 µm). Preliminary results show that urban drainage systems transport different loads of at least four microplastic types; namely polyethylene (PE), styrene-butadiene rubber (SBR)[1], polypropylene (PP) and polystyrene (PS). High PE concentrations are detected in all stormwater samples, followed by SBR, a main tire wear constituent. SBR loads showed dependency to the number of dry-weather days prior to sampled rain events.

Keywords: Microplastic, sampling strategies, separate sewer systems, WWTP

1. Introduction

Microplastic particles of urban origin have heterogeneous properties based on type, shapes, sizes and densities. These properties are prone to further changes due to varying weathering conditions [1]. Urban drainage systems are complex and comprise multiple transport, retention and treatment elements working together to achieve the objectives of urban wastewater management. Therefore, designing and implementing a monitoring strategy to track the sources and transport pathways is rather complex, and implies studying different wastewater streams separately.

Many studies, including an early phase of this research, showed that municipal wastewater treatment plants with tertiary treatment aggregates can remove 96-99% of all microplastic entering the plants during dry-weather conditions [2] [3] [4].

Unlike the dry-weather flow where the entire volume of wastewater is expected to be treated at WWTPs, stormwater runoffs could experience a different fate in the drainage system. Depending on rain event characteristics and the size, or even availability, of the retention facilities, stormwater runoffs are discharged into receiving waters with limited or no treatment. Recent studies suggests that stormwater runoff is probably the most significant transport pathway, where depositions of microplastic particles are remobilized and introduced into the sewer system. [5]

The main goal of this ongoing research is to develop and verify sampling strategies to monitor urban wastewater systems and to quantify microplastic emissions of selected catchment areas under different weather conditions. In this article, only sampling of rainwater runoff of an urban catchment area with separate drainage system is discussed.

2. Sampling of stormwater runoff of an urban catchment area with separate drainage system

2.1. Catchment area and sampling point

[1] By definition, the term plastics covers only thermoplastics and thermosets, but not elastomers, e.g. SBR. These materials can also release microparticles that are identified as synthetic polymers. For simplification, all the materials mentioned above are colloquially summarized by the term microplastics .

The catchment area is located in a residential area to the southeast of Kaiserslautern, Germany (49°25'00.2"N 7°41'44.7"E) and served by a separate sewer drainage system. The catchment area has a total area of 16.93 ha [A_T] and the *effective impervious area* counts for 6.67 ha [A_{EIA}]. All public sewer pipes (conduits) are made from reinforced concrete and have a total length of 3.5 km, no information about the private sewer pipes is available.

The sampling takes place at the outlet point of the catchment area in the inflow pipe (Ø 800 mm) of a stormwater retention tank (4,700 m^3).

2.2. Sampling concept

A new autonomous sampling concept was designed and implemented to capture large amounts of volume-proportionally samples from single or multiple rain events. A flow measurement system (NivuFlow 750, NIVUS GmbH, Eppingen Germany) is installed in the sampling pipe about 3m upstream the sampling hose and sends digital switching signals of the volume-proportionally runoff to a control unit (Siemens LOGO). In case of precipitation event, an external rain sensor (REGME, B+B Thermo-Technik GmbH, Donaueschingen, Germany) activates the control unit and starts a hose pump (Ponndorf P-Classic 35, Kassel, Germany) for 15-55 sec per switching signal. Sampling cycles continue either till the rain event ends or if the stainless-steel sampling tank (1,100 L) is completely filled. Based on previous flow measurements and the relatively small catchment area, sampling parameters were set to sample up to 1,200 m^3 of stormwater runoff (1 sampling cycle every 10 m^3 for 35 sec).
The sampling area is monitored continuously using a security camera (blink mini, LLC) equipped with a motion detector to capture every sampling cycle and increase the representativity of the whole sampling processes.

2.3. Sample preparation and detection

Due to the required large sample volumes (<1000 L), sample preparation starts in situ by stirring the sample using a metal rod for 5-10 min then a sub-sample (≈ 1 L) is taken for TSS and COD analyses. The entire sample is then sieved through a sieve cascade (1000, 500, 100, 50 µm) (Retsch GmbH, Haan, Germany) while stirring the sample till the end. To avoid the build-up of filter cake, sieving is halted many times, the sieves were backwashedand wet sediments were captured in glass bottles (DUran®, Duran group, Mainz, Germany). About 30 Lof the filtrate is captured to proceed with fine sieving in the laboratory. In the laboratory, samples are sterilized in (VARIOKLAV 75 S, HP Labortechnik GmbH) and dried in Teflon® plates at 105 °C in a compartment drier. To avoid cross-contamination, all samples are preserved and transported in plastic free instruments (Teflon or glass). The filtrate of the sample <50 µm is stored in the aqueous phase at 4 °C to be later sieved using a filter crucible which is designed to fit into TED-GC/MS [6].

Prepared samples are then analyzed using TED-GC/MS [2].

3. Results and Discussion

During the time period from July 2020 to February 2021, eight runoff samples were captured. Each sample represents at least one to three rain events separated by a no-rain period of 3 hours. Due to technical issues, more rain events in the mentioned period couldn´t be sampled sufficiently.

The early results show that polyethylene (PE) is the most detected polymer in stormwater runoffs (Fig. 1) (Tab. 1), followed by styrene-butadiene rubber (SBR), a main component in tire materials. PE concentrations occurred in all samples in relatively high averaged concentrations (44-249 µg/L) regardless of the rain characteristics and number of dry days before rain event. In contrast, SBR concentrations showed a strong dependency to number of dry-weather days prior to rain event (9-88 µg/L) (Tab. 1). In comparison to earlier results of wastewater sampling in a stormwater retention tank during dry-weather conditions, no SBR was detected. However, traces of SBR were detected in the influent of the central WWTP during dry-weather conditions (0-18 µg/L). An explanation for that would be the large stormwater retention capacity within the drainage system, which significantly delays the discharge of captured stormwater or that the polymer dilution in the stormwater retention tank is larger than in the WWTP influent and hence, is below the limit of detection with 0.12 µg.

While traces of PP and PS are detected, PET and acrylates are not detected in any sample.

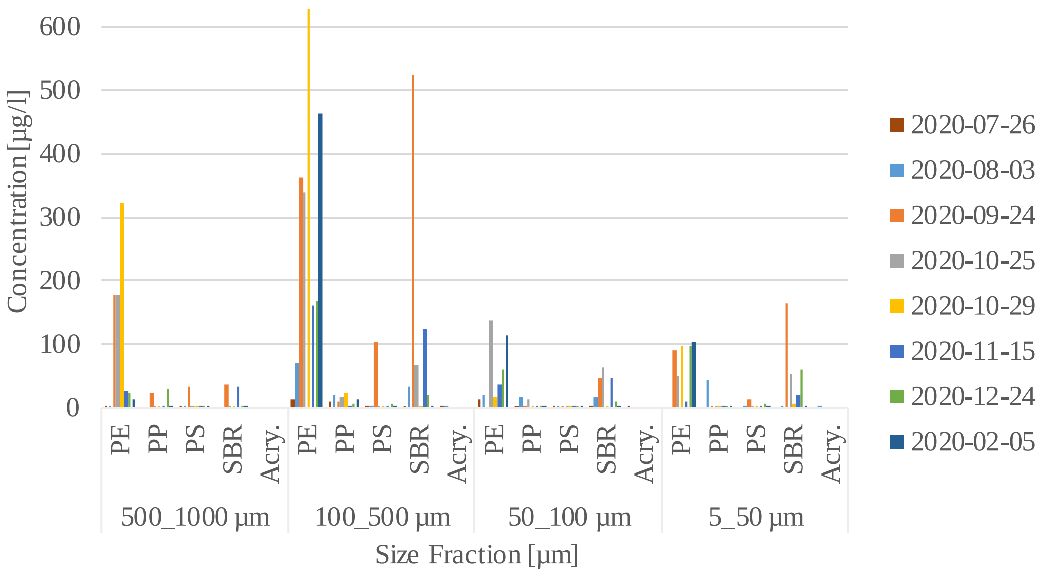

Figure 1. Concentrations of microplastic (PE, PP, PS, SBR and Acrylates) in all rain events per size fraction

Considering the absolute loads of all microplastic in all samples, 60% of the total microplastic load is found in the size fraction [100-500 µm], while 14%, 11% and 15% in the size fractions [500-1000 µm], [50-100 µm] and [5-50 µm] respectively.

However, taking into account the mass percent of all microplastic in each sample to the mass of dry fraction, it was found that microplastic count for 2.3%, 1.9%, 1.6% and 1.8% in the fractions [500-1000 µm], [100-500 µm], and [5-50 µm] and [5-50 µm] respectively (Fig. 2).

In 8 rainfall events from 2020-07 till 2021-02, it can be estimated that at least 429 $g_{.MP}/ha_{.EIA}$ (n=8) were transported through the separate drainage system. However, the sampled stormwater runoffs represent about 4460 m^3 (10%) of the yearly total stormwater runoff measured in 2020 ($Q_{sum.2020}$ = 45,679 m^3). With more data covering the entire year or even multiple years, yearly loads of microplastic per hectar of effective impervious area (EIA) can be derived and statistically modified.

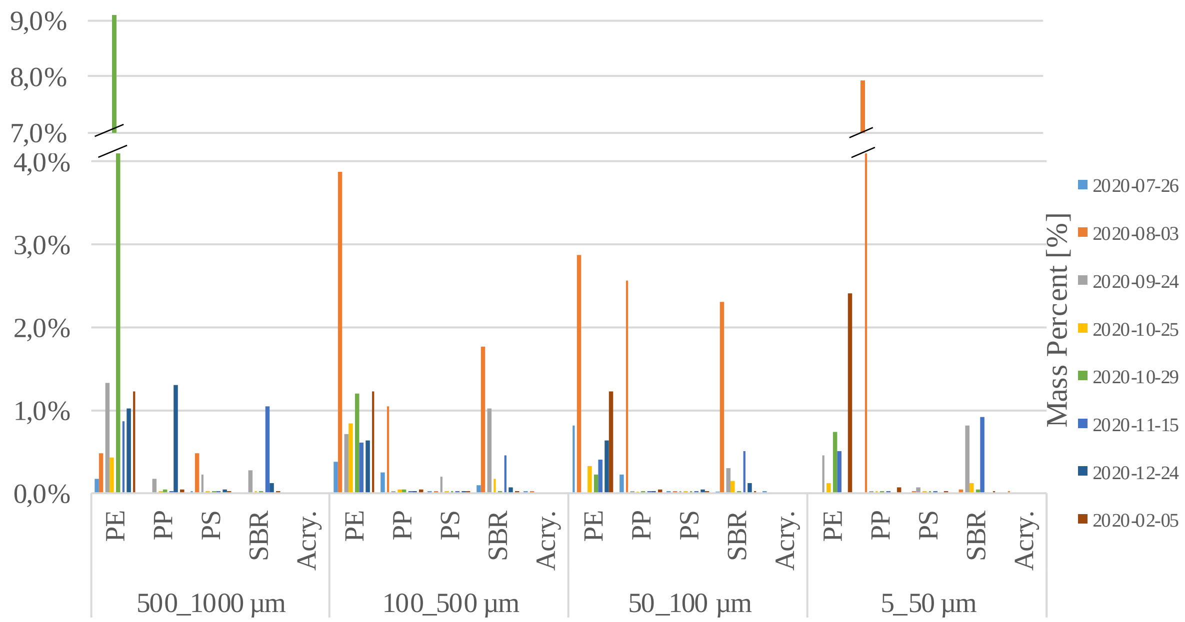

Figure 2. Mass percent of microplastic (PE, PP, PS, SBR and Acrylates) to total sediments per size fraction [µm] (n=8)

Table 1. Total microplastic loads, loads of SBR and PE and the mass percentage of SBR and PE.

Date	Total load	Rainfall runoff Volume	SBR		PE		Number of dry-weather days before rain event [h<1 mm]
	Einheit?	in m^3	in g	%	in g	in %	in days
2020-07-26	15,6	352	1,4	9,1	9,7	62,3	0
2020-08-03	29,1	133	6,4	22,0	12,0	41,2	7
2020-09-24	865,8	544	420,4	48,6	343,4	39,7	6*
2020-10-25	262,4	284	51,9	19,8	200,3	76,3	2
2020-10-29	554,3	503	4,0	0,7	535,5	96,6	0
2020-11-15	381,4	821	182,0	47,7	193,5	50,7	7
2020-12.24	304,5	607	57,8	19,0	210,7	69,2	0
2021-02-05	878,9	1216	4,0	0,5	696,5	79,2	0

* *Excluding the one rain event on the 16th of September, a total of 22 dry-weather days were registered prior to the sampling day*

4. Conclusions and future work

Sampling of microplastic in municipal drainage systems is a complex issue the many preparation and analytical steps involved. Roughly estimated, each sample requires 1 week of time form sampling till the end of the detection – which is quick with respect to other investigation procedures, because no sample preparation had to be done.
In our investigations PE is present and the main plastic representative in high concentrations and in all samples and size fractions. However, due to the fact that its occurrence in the runoff is independent from environmental conditions, we suggest that the sources are located within the sewer system in the public and private parts. SBR occurrence is, on the other hand, affected highly by the density of traffic and it is expected to be continuously flushed out of the system.
The sampling at this location and other locations with other wastewater streams is continued to validate and extend the current knowledge.

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Abbreviations

PE, Polyethylene; *SBR*, styrene-butadiene rubber; *PP*, Polypropylene; *PS*, Polystyrene; *WWTP*, Wastewater treatment plant; *TED-GC/MS*, Thermal desorption gas chromatography mass spectrometry.

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