"The Plastic Era": The effectiveness of litterbooms in trapping microplastics

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ABSTRACT

Plastic materials come in all shapes and sizes, negatively impacting the environment when improperly discarded. Scientists have recently become concerned with microplastic (MP) waste (<5mm) in freshwater environments. In recent years litterbooms have been designed and installed in rivers across the globe to collect floating plastics, where studies have been conducted to determine their effectiveness in collecting macro-plastics. However, little is known about how these mechanisms influence MP abundance in the water column and sediments in riverine environments. Furthermore, only a few studies have been done on quantifying and characterising MPs in riverine environments. This paper aims to address these issues by providing insights into the influence of the Quarry Road litterboom on MP abundance and the quantity and morphology of MPs in the Umgeni River, Durban, South Africa.

HIGHLIGHTS

- In the sediment samples a greater amount of low-density foam and film particles were found as compared to that of surface water samples.
- High amounts of MPs ranging from 100-250 µm are present in both surface water and sediment, increasing the possibility of ingestion by aquatic species.
- The concentration of MPs was higher at the litterboom as compared to the MPs upstream and downstream of the litterboom
- The litterboom does not trap MPs, but litterbooms affect MPs retention and settling time.

KEYWORDS

Microplastic (MP), Litterbooms, Umgeni River

INTRODUCTION

Across the world, plastic is a commonly used material. Many everyday items contain plastic and it has therefore become a part of our daily lives. The dependence on plastic has resulted in a significant increase in waste generation, resulting in widespread plastic pollution owing to waste mismanagement. Plastics are commonly used for packaging, construction, the automobile industry, electrical and electronic equipment, and recreational items (Hahladakis *et al.,* 2018) because they are lightweight, flexible and affordable. However, only 9% of plastic waste (PW) is recycled (Geyer *et al.,* 2017); therefore, most of the plastic is taken to landfills or dumped in the environment, ultimately entering rivers, lakes, and oceans. According to Lebreton and Andrady (2019), in 2015, mismanaged PW was approximately 52 000 000, 17 000 000, and 8 000 000 metric tons for Asia, Africa, and America, respectively. As a result, water quality is diminished, habitats are destroyed and the risk of entanglement and ingestion of MPs by aquatic species increases.

Plastic pollution has become an omnipresent environmental problem that has attracted much attention (Brighty *et al.,* 2017). However, in developing countries like South Africa, where PW management is inadequate, there is a high potential for PW to enter riverine environments. South Africa recycled 321600 tons of plastic in 2020, 11% less than in 2019 (Plastics SA, 2021). The remaining PW is landfilled or openly dumped (Hankel and Burgess, 2019). Furthermore, some of the created PW remains uncollected in developing countries due to a lack of regular waste management services or insufficient collection services (Ferronato and Torretta, 2019). As a result, PW can get blown and washed away from dumping sites as well as carried away by scavengers and dumped by informal settlers resulting in the re-littering of the environment, clogged drains, entering waterways, harming aquatic species, and breaking down into MPs (<5mm).

MP particles are classified into two types based on their origin: (1) primary MPs and (2) secondary MPs. Primary MPs are polymer particles created for further processing or added to goods to improve their capabilities. For example, microbeads in cosmetics and personal care products improve or increase the abrasive effect of exfoliation and cleaning properties of the products (Juliano and Magrini, 2017). More than 1 500 000 tons of primary MPs enter the ocean annually (Boucher and Friot, 2017). Microbeads are flushed down sinks, enter wastewater treatment plants (WWTPs), and eventually enter natural rivers and oceans (Cole *et al.,* 2011). Secondary MPs are the unintentional introduction of plastic particles into water bodies from existing macro-plastics in the river, resulting from solar radiation, wind, and mechanical breakdown (Boucher and Friot 2017). However, it is essential to note that environmental fragmentation of various plastic kinds and shapes will occur at varying rates, with thinner plastic fragments likely to break down more quickly (Rhodes, 2018). Synthetic textiles and clothing are significant producers of MPs, considering that during laundry, abrasion from chemicals and detergents cause synthetic fibres to break down into smaller micro-fibres (Browne, 2015).

The yearly inflow of plastic from rivers into oceans is estimated to be between 1.15 and 4 million tons (Miliute-Plepiene *et al.,* 2018), mainly occurring between May and October (Lebreton *et al.,* 2017). Compared to marine settings, freshwater systems have received less attention for plastic pollution (Wagner *et al.,* 2014; Eerkes-Medrano *et al.,* 2015), but recent research has shown rivers to be the primary route for the transmission of plastics into the ocean (Schmidt *et al.,* 2017; Lebreton *et al.,* 2017; Rochman, 2018). Between 2004 and 2016, it was calculated that between 0.41 and 4 million metric tons of PW from riverine environments entered the ocean yearly (Schmidt *et al.,* 2017). The relative contributions of individual river systems to global plastic emissions are altered as additional information on the prevalence and density of plastic pollution becomes available; however, recent research estimates that over 1000 rivers account for 80% of the world's annual plastic emissions (Meijer *et al.,* 2021). Globally, rivers transport land-based plastic into the oceans; however, this plastic also adversely affects riverine environments (van Emmerik and Schwarz, 2020) by destroying ecosystems (Sarkar *et al.,* 2021). This implies that further research in freshwater needs to be conducted. To this end, this research focuses on quantifying MPs and identifying them- by size and morphology, which is valuable information for governments, environmentalists, and engineers to develop suitable strategies to combat MP pollution in the Umgeni River.

In South Africa, the flow of plastic pollution from the Umgeni River into the ocean has been frequently recorded, although not formally documented or quantified (e.g., https://www.businessinsider.co.za/shocking-footage-caught-tons-of-plastic-crashing-in-the-waves-off-durban-following-heavy-rains-2019-12). Cameron Service created the litterboom initiative in 2017 to combat the rise in marine plastic waste by focusing on river systems rather than just the seas (The Litterboom Project, 2020). A non-profit organisation, the Durban Green Corridors has installed and continuously maintains litterbooms along the Umgeni river that flows within Durban. Litterbooms collect floating litter, which has proven to be a cost-effective, flexible, and scalable method for monitoring macro-litter in rivers (Miliute-Plepiene *et al.,* 2018). The litter booms can provide accurate and robust data on plastics that can allow for the quantification, categorisation, and analysis of macro-plastics in rivers for monitoring purposes that can later be used to develop or improve plastic reduction and collection strategies. However, research on how these booms influence MP pollution, accumulation, abundance, and transport is scarce; therefore, much more research is required to fully understand MP quantities. This study aims to determine the influence of the Quarry Road litterboom on MP abundance in the Umgeni River in Durban, South Africa.

PILOT STUDY

The pilot study was conducted at the Quarry Road litterboom with the aim of determining the optimal sample volume and mass for adequately quantifying MPs. Samples of different water volumes and sediment mass were collected at random points upstream and downstream of the litterboom to maximize sampling efficiency, conducted near the site chosen for the actual study. A total of five water samples were collected in 100ml, 350ml, 800ml, 1000ml and 1800ml bottles and returned to the laboratory. Further, 8000ml and 40 000ml of surface water were sieved onsite using non-metal sieves and a stainless steel bucket (8.5 litres). Each sample was filtered and visually inspected at four times magnification under the microscope. Upon visual quantification each surface water sample showed a MP number of 6, 22, 41, 163, 147, and 111, respectively. Four sediment samples were collected using a corer, with wet weight being 18g, 1008.1g, 2091.5g, and 4198.8g. Plastic was separated from sediment in each sample by flotation and filtration and filters were inspected visually using a microscope at four times magnification. The wet sediment was air-dried on foil for 24 hours and then oven-dried in foil containers at 50°C for 48 hours. Once dried, the sediment was weighed using a balance. The dry sediment weighed 14.9g, 852.5g, 1738.8g, and 3505g, which contained an MP number of 249, 5522, 6217, and 2087, respectively. Results showed that 1800ml of surface water and 1738.8g of sediment contained the highest peaks of MPs and, therefore, would be the most efficient for subsequent collection. However, to make sampling more convenient, the sample volume and mass were rounded off to 2000ml and 2000g, respectively.

METHODOLOGY

The study's aims were: (1) MP quantification and identification (by size and morphology) in the surface water and sediment upstream of the Quarry Road litterboom and (2) To determine the influence of the Quarry Road litterboom on MP abundance in the surface water and sediment. The research objectives were: (1) to quantify the MP abundance in the sediment and water column upstream, directly adjacent to the downstream of the Quarry Road litterboom (2) to determine the most prevalent sizes and forms of MP at each sampling site and (3) to determine the influence of the Quarry Road litterboom on MP abundance.

Sampling

Sampling for aim 1 and objectives 1 and 2

In order to determine the quantity and most prevalent form and size of MPs upstream of the Quarry Road litterboom, three sediment samples using a scoop and surface water samples were taken at 3 points along the litterboom, namely; near bank, mid-stream and far bank once every week for a month (26th October 2021, 8th, 15th and 22nd November 2021 and 14th March 2022). Water samples were collected in 1 litre glass bottles and sediment was collected in 350 ml glass jars. This provides insights into how much MPs accumulate immediately at the litterboom in the surface water and sediment. An additional sample was collected in March 2022 to estimate changes in abundance that occurred.

Sampling for aim 2 and objectives 3

In order to determine the influences of the Quarry Road litterboom on MP abundance and gain insight about abundance at different distances from the litterboom, a once-off sampling on 14th March 2022 was conducted, consisting of 30 sediment and 30 surface water samples. This consisted of samples taken at the litterboom and 5m and 10m upstream and 5m,10m, and 20m downstream from the litterboom. Sediment samples were collected using a corer and stored in 250mm x 400mm plastic packets and surface water in glass jars.

Laboratory Processing of samples

During laboratory processing, only glass and metal were used when handling samples to avoid contamination. The filtration tower, glass petri dishes, metal buckets with lids, forceps, non-metal sieves (100, 250, 500 and 1000 μm), and wooden sticks were washed and placed upside down to air dry in preparation for sample processing. Once the petri dishes were dry, they were inspected under the microscope for contamination. If the petri dish was not contaminated, a reinforced glass fibre filter paper (47 mm in diameter and pore size of 1 μm) was examined under the microscope for contamination; if no contamination was present, it was placed in the inspected petri dish. This process was repeated for each set of samples processed. An Excel spreadsheet was created for MP data to be entered upon visual inspection under the microscope.

Furthermore, three controls were set up to test for MP contamination from the sieves made from PVC and nylon mesh, the salt solution used during flotation and plastic packets used to transport sediment during sampling. The sieves were washed and left upside down to air dry. Once dried, the sieves were visually analysed under the microscope for contamination. The sieves were rewashed and checked under the microscope to see if contamination occurred. If no contamination occurred, 10 litres of Millipore water was poured through the sieves over a metal bucket, then filtered. The plastic packets were filled with Millipore water, left aside for a month, and underwent filtration. The salt solution was mixed and filtered using a filtration tower. All filter papers were visually examined under the microscope for the quantification of MP particles. If contamination occurred, the average was taken from the three controls and subtracted from the total of the sample filters to ensure accurate values were presented.

Water samples were poured through sieves over a metal bucket; the sieves were then covered with foil to avoid contamination from airborne particles. The sample in the metal bucket was poured through the filtration tower to collect particles < 100 µm in size. The filter was placed in the glass petri dishes, covered, labelled, and left aside. Next, each sieve was placed upside down in a clean glass beaker where Millipore water was sprayed on the sieve to loosen the particles stuck to the sieve. Once all particles were removed, the solution was filtered using the filtration tower to collect the particles on the filter paper, which was then transferred to a glass petri dish. Once all processing was complete, the filters were examined under the microscope at four times magnification and visually quantified according to morphology (pellet, film, fragments, line, fibre, foam) and size based on the sieve size. The quantities of each were then entered onto an excel spreadsheet.

A salt solution consisting of 140g of salt per liter of Millipore water was used for floatation to separate MPs from the sediment. Each sediment sample was placed into a metal bucket, and twice the amount of salt solution as sediment was added and stirred with a wooden rod for two minutes to allow plastic particles to become suspended. Each sample underwent six suspensions with a waiting period of 24 hours to settle. The supernatant was carefully poured through sieves over a bucket and then poured back into the respective sediment sample each time. Once all six were complete, the salt solution was filtered and examined for <100 µm MPs under the microscope. Each sieve was washed with Millipore water over a glass beaker to remove all particles and undergo filtration to be visually examined under the microscope. This process was repeated for each sediment sample.

Data Analysis

Data analysis was performed using Microsoft Excel, where individual spreadsheets were created for the accumulation and effect of the litterboom. This data was entered as the particle was identified and quantified by count during visual inspection.

RESULTS AND DISCUSSION

Table 1: Total weekly accumulation of MPs in surface water and sediment at Quarry Road Litterboom

Sample date (DD/MM/YYYY)	Rainfall (mm)	Total number of MPs in surface water (per 3 L)	Percentage of the total number of MPs in surface water	Total number of MPs in sediment (per 1.05g)	Percentage of the total number of MPs in sediment
26/10/2021	15	557	14	518	25
8/11/2021	45	645	16	392	19
15/11/2021	13	1072	26	438	21
22/11/2021	33	1248	30	388	19
14/03/2022	419	599	14	310	15

Total	525	4141	100	2046	100

Notes: a) MP value is the total number of MPs per 3 litres (surface water) and 1.05 g (sediment)
b) Rainfall value is accumulated rainfall between sampling dates

Table 1: Total MP accumulation for all five weeks at the three points along the Quarry Road litterboom by count and percentage. The abundance of MPs in the surface water were 557, 645, 1072, 1248, and 599 and in the sediment was 518, 392, 438, 388, and 310 for each week. In October (week 1) and November (week 2, 3, 4) 2021, the MP accumulation in surface water gradually increased by 2%, 10%, and 4%, respectively, while accumulation fluctuated in the sediment with a 6% decrease, 2% increase and 2% decrease respectively. During this period, rainfall fluctuated with a 30mm increase, 32mm decrease and 20mm increase. In March 2022, 419mm in rainfall occurred from the last sampling date (22/11/2021). However, a decrease in accumulation occurred in surface water and sediment by 16% and 4%, respectively. This is a result of the rainfall experienced since the rainfall allows the MPs to flow further downstream before they have enough time to sink and settle in the sediment. However, the presence of MP in the sediment indicates that bigger particles will sink and accumulate in the sediment even with rainfall.

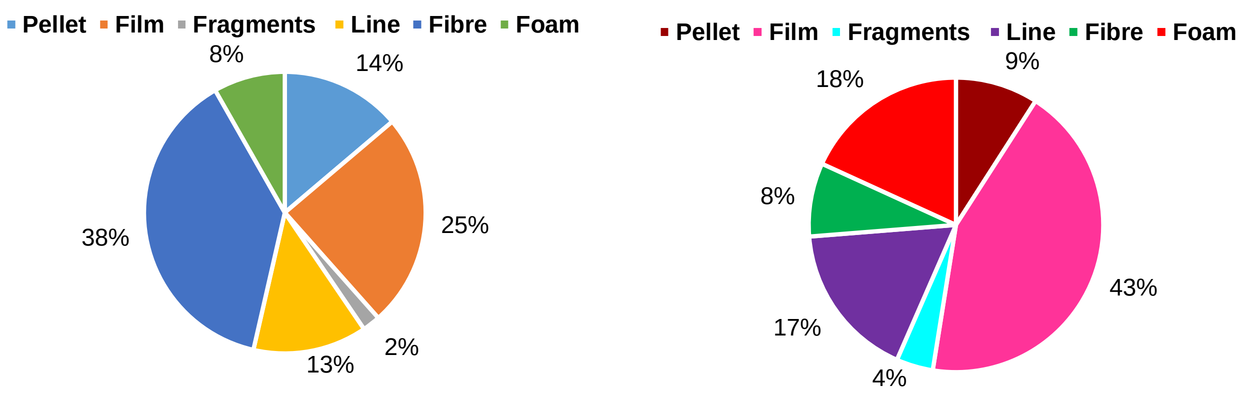

Figure 1: MP morphology proportions in surface water (Left) and sediment (Right) (For all samples collected)

Based on figure 1, the different morphology of MPs identified were pellets, films, lines, fibres, fragments, and foam. In surface water, film and fibre were most prevalent, while foam and film were most common in the sediment. Films originate from plastic items that have been torn of thin, lightweight plastics such as plastic bags. Since high levels of microfilm were present in both water and sediment samples, it is an indicator of poor waste management. Plastic bags can be blown into the river from roads, storm water drains, and illegal waste dumps created by informal settlements along the Umgeni River. A possible cause of low-density films found in the sediment is biofouling; since the plastics persist in the river, these particles will accumulate several foulants on their surface, increasing their density and causing them to sink to the sediment.

Karbalaei et al. (2018) show that fibres are primarily prevalent in sediment. However, results indicated that more fibres are present in the surface water of the Umgeni River, indicating that the fibres present in the sediment were suspended due to weather changes such as heavy rainfall that increased the river's water level and flow, which may increase turbidity and cause swift currents. Along the Umgeni River, several informal settlements, residential areas, and WWTPs are present, which are the primary sources of microfiber particles arising from laundry being washed directly in the river by informal communities and wastewater from machine washing being emitted from effluents from WWTPs. Foam is lightweight and highly buoyant, indicating a high chance of its presence in surface water; however, results indicate that foam is the second most prevalent MP shape in the sediment. The presence of foam on the riverbed is often caused due to the growth of algae, barnacles, or other tiny organisms on the surface of the particle, causing it to sink to the sediment.

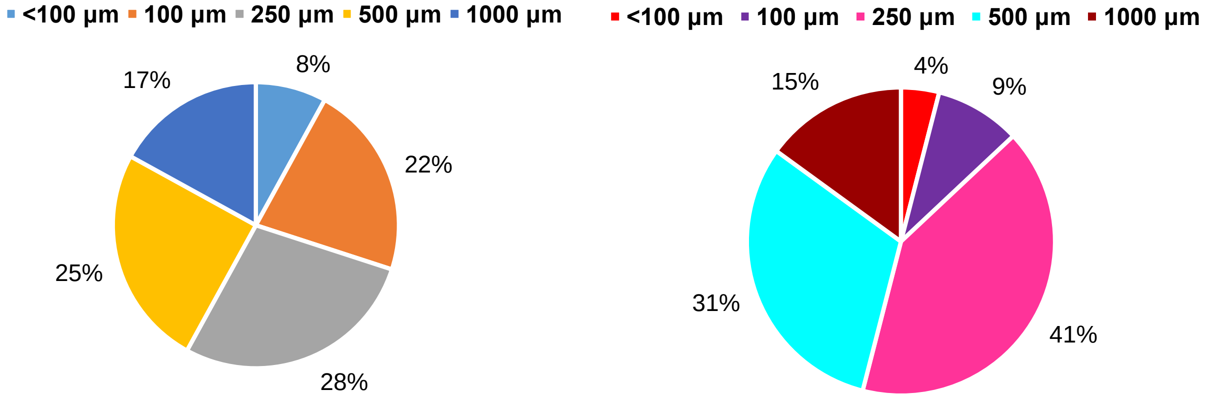

Figure 2: MP size accumulation in surface water (Left) and sediment (Right) (For all samples collected)

The extracted particles in this study were classified into five size categories according to sieve size, as shown in Figure 2. These sizes were <100, 100, 250, 500 and 1000 µm. These results indicate that 250 and 500 µm particles are the most common along the litterboom in surface water and sediment. According to Rodríguez-Sejio and Pereira (2017), MP ingestion is primarily determined by size and abundance compared to colour and occurs by chance. Therefore, understanding the size ranges of MPs in the Umgeni River is vital since MPs can be mistaken for food by animals who are likely to consume prey that is smaller than them in size. Furthermore, these particles are considered food by several aquatic species as some MPs are approximately the same size as planktons (Cole *et al.,* 2015).

According to Sherr and Sherr (2009), the majority of micro-plankton is approximately half a micron in size; however, 100-200 µm are the largest phytoplankton and protists. MPs present in the Umgeni River within this range amounted to 32% in surface water and 50% in the sediment by number, implying that aquatic species in the river are highly likely to be ingesting many MPs causing harm to a large number of organisms. Ingestion of these particles by organisms can cause build-up in the digestive tract, resulting in a false sensation of satiation or even perforation of the gastrointestinal tract if they are not small enough to pass through the organism's system. Furthermore, families from the informal settlements consume fish from the river, which exposes individuals to MPs and associated chemicals that can result in ill health. This is disadvantageous to the surrounding communities since they are financially constrained.

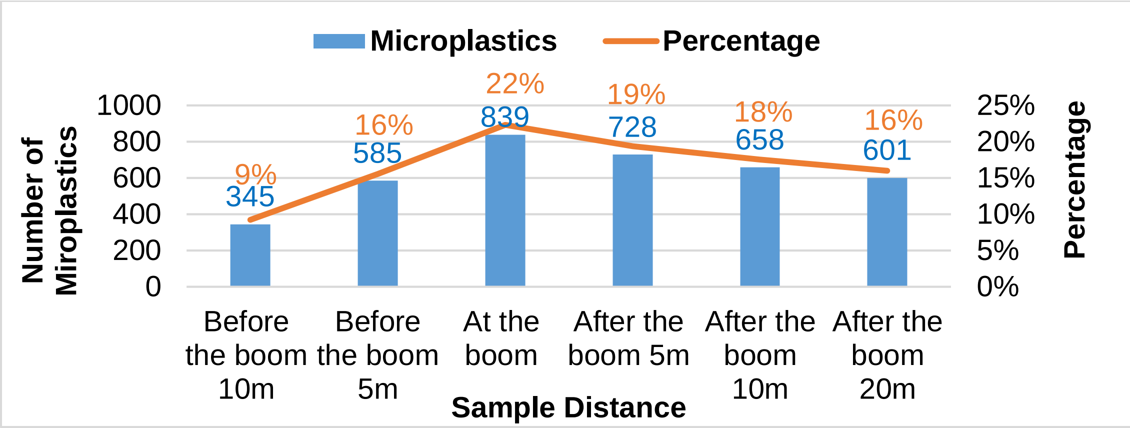

Figure 3: MP abundance in surface water at different distances from the Quarry Road Litterboom

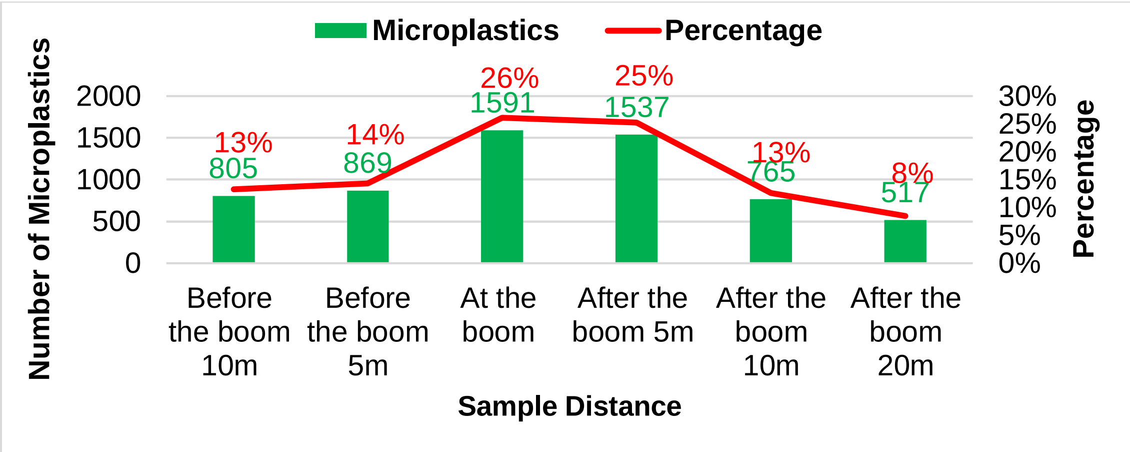

Figure 4: MP abundance in the sediment at different distances from the Quarry Road Litterboom

According to Helinski *et al.* (2021), booms are independently effective technologies for macroplastic capture. It is essential that these booms must be modelled based on the river characteristics to benefit MP capture. Several organisations installing litterbooms in riverine environments have stated that they do not trap MPs.

Based on Figure 3, the samples taken 10m and 5m before the litterboom represented 16% and 9% MP abundance, respectively. MP abundance at the litterboom amounted to 22%. The samples taken after the boom at 5m, 10m, and 20m consisted of 19%, 18%, and 16% MP abundance in surface water. Sediment samples taken before the boom consisted of 13% and 5% of the total MP abundance. The litterboom exhibited 26% of MP abundance. After the boom, abundance totals were 25%, 13%, and 8% (Figure 4). A greater quantity of MPs was found 5m before the boom compared to further away from the boom, which suggests that as MPs flow down the river, the macroplastic and the litterboom facilitate the accumulation of MPs at the boom. The presence of more MPs at the litterboom than before and after the boom suggests that the boom plays a role in retaining MPs. There are 31% more MPs in the sediment at the litterboom compared to surface water, suggesting that the accumulation of the macroplastic at the boom slows the transportation of MPs down the river giving more time for the MPs to settle into the sediment, hence the presence of more MPs on the river bed. This is further supported by the significant decline in MP concentrations 20m after the boom, suggesting the accumulation of larger plastics at the litterboom reduces the river flow velocity, allowing for more particles to settle into the sediment.

Once large amounts of MPs contaminate the riverbed, it poses a substantial danger to the health of the entire riverine ecosystem (Hurley *et al.,* 2018). The health of river bed habitats supports the entire river ecosystem as numerous animals rely on them to survive, feed, and reproduce. When these habitats are polluted with MPs, the ecosystem is exposed to those particles for a more extended period of time before they can be flushed away by flooding. Prolonged MP pollution on the riverbed increases the likelihood that aquatic organisms will absorb it and pass through the food chain. MPs can spread other wastewater pollutants and chemicals, which also pose an impact on the health of sediment, species, and surrounding settlements.

CONCLUSIONS

MPs are ubiquitous, and as more plastic is released into the environment, there is rising concern about the harm MP contamination may cause to the ecosystem and the possible health repercussions thereof. Numerous species mistake MPs for food, which can physically injure the organism and leak potentially dangerous chemicals into the environment. Understanding the morphology of MPs is essential in that it can assist with developing pollution prevention mechanisms. Furthermore, identifying the shapes can indicate the parent material of the MPs (Zhang *et al.,* 2018).

The fact that low-density film and foam particles, which are predicted to float on surface water, were found to be more predominant in the sediment suggests that other factors besides density influence the abundance of MPs in riverine habitats. In addition to biofouling (Andrady, 2011), natural substance adsorption to the particle surface (Frias *et al.,* 2010), the incorporation of inorganic fillers during production (Corcoran *et al.,* 2015), and faecal matter, these low-density particles could also be transported by current and deposited on the sediments (Cole *et al.,* 2015). The results on abundance indicate that large amounts of MPs resembling the size of plankton are present in the river posing a threat to the well-being of aquatic species and settlers surrounding the river. Although litterbooms do not trap MPs, the effect of the litterboom is that it concentrates MPs in the sediment 5m upstream and 5m downstream of the boom. In addition, the litterboom concentrates MPs in surface water 5m upstream and 20m downstream of the litterboom.

MP research is essential and more studies need to be conducted in South African rivers to assist researchers, developers, and governments in analysing MPs impacts, quantities, shapes, and sizes to facilitate the design and development of systems to collect MPs, thereby reducing the number of plastics entering our oceans. Furthermore, it can assist in reviewing the effectiveness of the litter booms and developing better systems to combat MP pollution in rivers.

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