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State-of-the-Art Microplastic Sampling Sources, Identification Approaches and Possible Transformation to Wealth

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Microplastics are defined as plastic particles of different shapes and polymer compositions, ranging in size from 1µm to 5 mm. There are two types of microplastics: primary microplastics, such as microbeads added to household products, and secondary microplastics, commonly used to make bottles and plastic bags. Microplastic pollution has become a major issue affecting human health. Research suggests that once humans ingest microplastics ranging from 0.1 to 10 µm, these particles can be absorbed by the blood-brain barrier and placenta. This can potentially cause damage to the circulatory system. This study aims to review the techniques used for sampling microplastics, including passive and active sampling. The review of microplastic articles encompasses sources from both indoor and outdoor environments, such as soil, water, and air. Research suggests that individuals who consume water from plastic bottles may ingest up to 90,000 microplastic particles annually. In addition, studies conducted in indoor environments, such as houses, dormitories, and offices, indicate that an individual can ingest approximately 190 microplastic particles per day and up to 69,000 particles per year due to the high abundance of microplastics indoors (1,583 ± 1,180 particles/m^3).This review also emphasizes the analytical methods employed by scientists to identify and characterize microplastics. For instance, visual observation (stereomicroscope), micro-Fourier transform infrared spectroscopy, laser direct infrared analysis, Raman spectroscopy, scanning electron microscopy, and mass spectrometry. Also, this review article explores the potential for transforming microplastics into valuable products through innovative recycling and upcycling methods.

1. Introduction

Microplastics (MPs) are defined as plastic particles with different shapes and polymer compositions ranging from 1 µm to 5 mm (Kek et al., 2024). There are two types of MPs such as primary MP and secondary MP. Primary MP are intentionally manufactured and incorporated into consumer products, such as the exfoliants used in synthetic clothes and microbeads added to personal care products for enhanced texture and efficacy. (Ziani et al., 2023). Synthetic fibers in clothing, which become MPs during washing processes, contribute significantly to environmental MP pollution (Hashim et al., 2023). On the other hand, secondary MP are the environmental breakdown of larger plastic items like bottles and packaging materials though weathering, fragmentation, and degradation. Common sources of secondary MPs include discarded plastic bottles, bags, and polystyrene containers from food halls and supermarkets, which fragment into smaller pieces over time. There are various shapes of MPs such as fibres, microbeads, fragments, foam, pellet, sheets and film (Marrone et al., 2021), as shown in Figure 1. The global plastic production statistics reveal significant environmental impacts, with China alone producing approximately 63.0 Mt of plastic in 2013, a figure that significantly increased when combined with other Asian countries to about 114 Mt (Ryan, 2015). Projections suggest a potential increase to 500 Mt by 2025 (Huang et al., 2021). MP pollution has become a major concern which can affect

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human health. Research shows that land-based sources contributes 80-90 % from the total number of outdoor MP pollution (Duis & Coors, 2016). These include inappropriate methods of disposal single-use-plastic such as polystyrene lunch boxes, plastic cups which are non- biodegradable in landfills. Golwala et al. (2021) indicate that from landfill plastic waste, approximately 0.31 % by weight can become airborne microplastics, equating to about 62 (±23) items per kg. On the other hand, ocean-based sources only contribute 10-20 % of total number of outdoor MP pollution (Karbalaei et al., 2019). For example, releasing petrochemicals by industries to the marine ecosystems, discarding plastic monofilament and nylon lines to the sea.

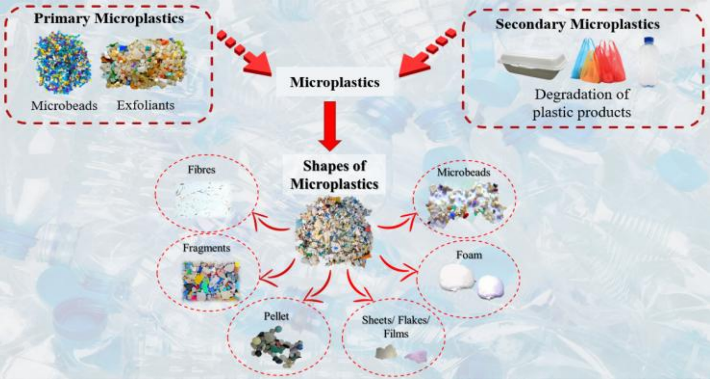

Figure 1: Types and shapes of MPs and examples of it. [Retrieved from Ziani et al. (2023)]

MP pollution is not only limited to outdoor, indoor MP pollution or known as airborne MP can affect human health. For example, placing a polystyrene lunch box in a manufacturing industry with high extreme temperature conditions can lead to breakdown of the MP particles into gases such as carbon dioxide and carbon monoxide. Once inhaled, MPs ranging from 0.1 to 10 μm can cross into the bloodstream, potentially causing vascular damage (Alexander et al., 2016). In addition, studies conducted in indoor environments, such as houses, dormitories, and offices suggests that individual ingest near to 190 MP particles one day and as high as 69,000 particles per year (1,583 ± 1,180 particles/m^3) which is significantly higher compared to outdoor exposure levels(189 ± 85 particles/m^3) (Liao et al., 2021). Another research indicates that the median contribution of MP particles are as high as 1.07×10^{-7} mg/capita/day in terms of mass of air (Mohamed et al., 2021). Despite extensive research, there remains a gap in the comprehensive understanding of MP sampling and analytical methods. This paper aims to present an overview of methods used in MP sampling such as passive and active MPs sampling in various environments. It examines the array of analytical approaches used to detect MPs, comprehensively discussing the advantages and disadvantages associated with each method. This review contributes to the field by not only compiling existing methods but by critically evaluating their effectiveness in different environmental contexts, identifying potential areas for methodological enhancements. The article explores the potential of innovative recycling and upcycling methods to transform MPs into valuable products.

2. MP Assessment Approach

Assessment of MP can be divided into two main stages: sampling and analysis (Kek et al., 2024). In the sampling stage, both passive and active methods are employed. Passive methods involve the collection of MPs using naturally occurring environmental processes, such as sedimentation, while active methods require the use of specialized equipment to actively gather samples from water bodies, sediments, or biota. Following collection, the samples undergo filtration treatment to isolate pure MPs, removing other particles and contaminants for further analysis. In the analytical phase, various techniques are employed to characterize the isolated MPs, including visual observation and chemical characterization. Visual observation, for instance, allows for the quick identification and preliminary sorting of larger MPs based on size, shape, and color. However, it cannot reliably detect smaller particles. Chemical characterization methods, such as Micro-Fourier Transform Infrared (μ-FTIR) spectroscopy, Raman spectroscopy, Scanning Electron Microscopy (SEM) and Laser Direct Infrared (LDIR) analysis, provide detailed information on the polymer composition of MPs.

Passive sampling is known as sampling by leaving the collecting device in a set environment for a period to allow MPs particles to accumulate naturally. To conduct this sampling method, adhesive tape, or sediment trap are left at a designated location for certain period of time ranging from days to months (Tian et al., 2017). The advantages of passive sampling is it reflects the natural distribution and accumulation of MPs over time The limitations of passive sampling method such as it is not suitable to be used in all environments such as small ponds where passive sampling not able to capture MPs particles effectively due to lack of water flow (Shao et al., 2022). Active MP sampling methods are the sampling that involves physical collection of the samples from environment using equipment such as nets or pumps. To conduct this sampling method, researchers actively navigate through the water or sediment, collecting samples at predetermined locations or depths. The advantage of active MP sampling is it provides more control over the sampling process, allowing researchers to target specific areas or depths of interest. The suitable method to characterize MPs in terms of shape and size by using appropriate filter treatment and analytical approaches are as summarised in Table 1. After filtration, the analytical phase involves a variety of techniques to characterize the samples. These methods include visual observation, which is limited to identifying MPs larger than a size of 10 µm, and chemical characterization that explores MPs down to much smaller sizes of 1 µm. The functionalities, advantages, and limitations of these analytical approaches are summarized in Table 2.

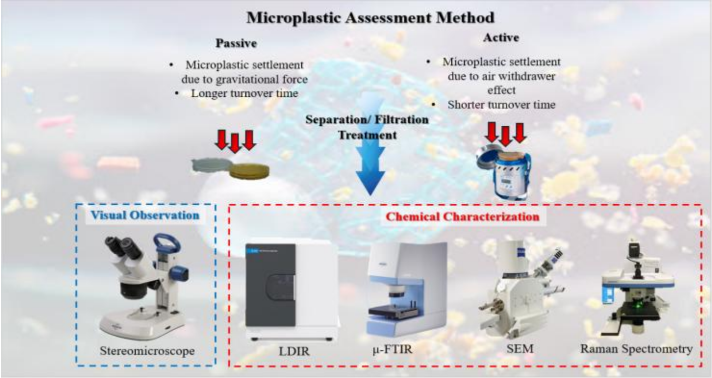

Figure 2: MPs Assessment Method

Table 1: Available data on filtering approach used to characterise MPs in terms of shape and size

Sampling Type	Sample Method	Location/Source	Filter	Analytical Approach	Shape	Size (µm)	References
Passive	Dry atmospheric deposition	Outdoor (Air)	Cellulose	Fluorescene+microscope µRaman	Fragments	< 63	Dris et al. (2017)
	Passive Sampling	Indoor (Air)	Mixed cellulose esters membrane (5 µm)	Stereomicroscope + µFTIR	Fibres	5-5,000	Jenner et al. (2021)
	Passive Sampling	Outdoor (Sea Water)	Glass filter (0.45 µm)	µ-Raman spectroscopy	Fragments	250–500	Picó and Barceló. (2019)
	Glass Container	Indoor (Tap Water)	Glass filter (0.45 µm)	µ-Raman spectroscopy+Visual Observation	Fragments	≥64	Sol et al. (2023)
		Outdoor (Soil)	Sieving	Stereomicroscope + µFTIR	Fibres, pellets, fragments and films	0–500	Zhang et al. (2022)
Active	Active pump sampler	Indoor (Air)	Glass filter (1.6 µm)	FTIR+ Visual Observation	Fibres	19–3,948	O'Brien et al. (2020)
	Active pump sampler	Outdoor (Air)	Mixed cellulose ester (0.8 µm)	SEM - EDX	Fibres	5-20	Li et al. (2020)
	Pumping	Indoor (Tap Water)	Glass filter (0.45 µm)	FTIR+ Visual Observation	Fibres	25->500	Sol et al. (2023)
	Pumping	Outdoor (Lake Water)	Glass filter (0.45 µm)	µ-Raman spectroscopy+Visual Observation	Sheets	11.2-50	Xiong, et al. (2019)

Table 2: Types of analytical approach carried out to characterize the MPs

Analytical Approach	Objective	Advantages	Limitations	References
Visual observation	To observe the samples with low magnification in x, y, z plane	Low chemical hazard is exposed to the researcher and low cost needed due to its simplicity	Not applicable due to its inability to visualize small environmental samples such as fibres have size thinner than 10 µm	Soltani et al. (2021)
Fourier Transform Infrared (µ-FTIR)	To measure the absorption of infrared radiation by MP	Able to provide specific information on chemical bonds and functional groups in samples	Limited to MP samples that having a size of <20 µm	Kim et al. (2018)
Laser Direct Infrared (LDIR)	Provide high sensitivity, allowing for the detection of amount of MPs from environmental samples	Can directly analyze MP samples on surfaces or in bulk samples	Limited to surface analysis and may not penetrate deeply in opaque samples and have limitation on detecting MP that have size (<20 µm)	Cui et al. (2022)
Raman spectroscopy	To analyse the vibration of molecules by measuring the scatter of monochromatic light	MP samples below 20 µm can be identified based on its inelastic scattering of light.	Long detection time for the MP sample is needed and not able to view MP samples that are < 1 µm	Dong et al. (2022)
Scanning Electron Microscopy	Provides high-resolution image of MP particles, allowing researchers to visualize the shape and size of the MPs	Able to analyse the surface morphology and element composition of MP simultaneously and able to view MP sample which have size of (<0.5 nm resolution)	Does not provide chemical composition data unless coupled with Energy Dispersive X-ray Spectroscopy. High cost is needed due to its complication in pre-treatment process	Chen et al. (2020), Fu (2020)

3. MP Mitigation Approach

Refill not Landfill, one of the ways to reduce the MP pollution is by advocating for the reuse of plastic bottles instead of discarding them after single use. Statistics indicate that if human embraced refilling plastic bottles, it can potentially slash up to 91,000 items/kg per year plastic bottle waste (Wojnowska-Baryła et al., 2022). Research also shows that recycling plastic waste from vehicles into graphene could prevent 350 kg of plastic waste from being landfilled (Pacchioni, 2022). There are a few methods to mitigate MP, such as closed-loop MP recycling and open-loop MP recycling. Closed-loop MP recycling is a method that collects plastic waste and remanufactures it into the same form of products (Xuehong et al., 2024). For example, collecting unused paper and remanufacturing it for the use of printing newspapers. Open loop MP recycling means that converting the waste product to a new raw material using different type of manufacturing process (Xiang and You, 2024). For example, converting plastic bottles waste into straw by applying pyrolysis process. Another avenue to curb MP waste is by converting them into valuable products. The current products produced through the upcycling of MPs are illustrated in Figure 3. MP can be repurposed as anodes in Na-ion batteries, exhibiting a high reversible capacity of 340 mAh/g at a current rate of 0.01 A/g (Tan et al., 2024). MP waste can be converted into biofuel through thermodegradation method, achieving an impressive maximum carbon conversion efficiency of 97 % within 1 h under operating conditions of 800 °C (Bai et al., 2020). Recycling MP waste into electrospun fibers offers a sustainable method to create high-performance materials for various applications, including filtration, textiles, and biomedical devices (Li et al., 2022). Upcycling MP waste into construction materials enhances mechanical properties such as durability and flexibility, providing sustainable alternatives for concrete, asphalt, composite materials, and paving blocks (Kek et al., 2024), further promoting environmental sustainability in the construction industry. This approach had fulfilled Sustainable Development Goals (SDGs) by aligning with SDG 12: Responsible Consumption and Production, by upcycling MP to construction materials such as paints, cement, plastic pipes, glass, etc. to reduce the usage of new materials. In addition, this approach aligns with SDG 14: Live Below Water by promoting the recycling of nylon line which is a type of ocean based plastic waste to be recycled into materials such as recycled bags, laundry bags which is reusable to reduce the disposing of ocean based MP waste into the ocean that potentially cause harmful to the aquatic life.

Figure 3: MP waste transform to value added products

4. Conclusions

In conclusion, this review highlights the urgent need to address MP pollution, which poses a significant threat to environmental health. By exploring sampling sources, identification methods, and potential transformations into wealth, the review emphasizes the importance of understanding the distribution and impact of MPs across ecosystems. By identifying various sampling sources, including water bodies, sediments, soils, and air, researchers can better understand the extent and distribution of MPs across different ecosystems. In this context, passive and active sampling methods offer valuable tools for collecting representative MP samples. Advanced identification approaches, ranging from visual microscopy to advanced spectroscopic and imaging techniques, enable researchers to accurately characterize MPs. Despite notable advancements, challenges such as method standardization, detection limits, and distinguishing MPs from natural particles still persist. This review highlights the transformative potential of MP waste through recycling and upcycling initiatives. By converting MPs into valuable products such as graphene, batteries, biofuel, fibers and construction materials, researchers can mitigate pollution while creating economic opportunities. Future efforts should focus on standardizing methodologies, enhancing detection sensitivity, and advancing techniques for accurate identification. Collaborative research across disciplines is crucial to develop sustainable solutions that protect ecosystems, promote circular economy principles, and safeguard human health.

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