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Microfiber Waste Assessment for an Italian Textile Dyeing Company

Sinem Hazal Akyildiz[1]*, Valentina Balestra[1], Paola Marini[1], Rossana Bellopede[1]

Abstract

The textile industry plays a substantial role in causing environmental pollution, specifically by generating textile waste, which consists of both macro and micro waste. Microfibers (MFs), which are typically less than 5 mm in length, are discharged into the environment at different stages in textile manufacturing, especially during wet processes. Textile dyeing processes are recognized for emitting substantial amounts of MFs, which present notable environmental risks. Synthetic microfibers can accumulate in various ecosystems and persist in the environment for extended periods. Furthermore, it has been discovered that MFs possess the ability to absorb detrimental chemicals and pollutants, which can endanger aquatic organisms and potentially infiltrate the food chain, thereby having potential consequences for human well-being. This study examines the amount of MFs released by an Italian dyeing company during each operation, encompassing underground water used in the process, inflow and outflow wastewater, and sludge. By utilizing the ISO 4484-2 standard for sample pretreatment, MFs separation, and identification, the research aims to accurately measure the quantity of MFs at every stage. The findings clarify the relative impact of each stage on the total release of MFs and evaluate the efficiency of the existing wastewater treatment system in capturing MFs. By addressing the challenges posed by MF pollution, the textile industry can take significant strides towards minimizing its environmental footprint and promoting sustainable practices.

Keywords: Microfiber pollution, textile dyeing process, wastewater, wastewater treatment plant, micro-FTIR.

1. INTRODUCTION

Microfibers (MFs), which are synthetic fibers that are less than 5 mm in length [1], are becoming more widely acknowledged as a substantial environmental pollutant, particularly in aquatic ecosystems. The textile industry is a significant contributor to the discharge of these microfibers into the environment, particularly during the dyeing and laundering processes. Research indicates that microfibers are not only released during the washing of textiles but are also present in the fabric prior to washing, suggesting that the manufacturing processes themselves contribute to this pollution [2].

The releasing of microfibers can be further exacerbated by the dyeing procedure. The fibers may become more susceptible to shedding during washing as a result of the compounds used in dyeing, such as dyes and additives

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[3]. Furthermore, the potential for these microfibers to serve as vectors for hazardous substances, thereby enhancing their environmental impact, is a cause for concern due to the presence of toxic compounds in dyed textiles [4].

The environmental impact of microfiber contamination is significant. Microfibers can be consumed by a variety of aquatic organisms, including zooplankton, larger fish, and birds, potentially leading to bioaccumulation in food webs [5]. This ingestion endangers not only marine life but also human health, as microfibers can enter the human food chain via seafood intake [6]. Polyester microfibers are one of the most prevalent kinds of microplastics detected in the environment, highlighting the need for effective mitigation techniques [7].

Efforts to reduce microfiber contamination from textile dyeing and manufacturing are critical. Strategies such as improving wastewater treatment procedures, producing biodegradable fabrics, and using better design principles in textile production can all assist to limit microfiber discharge into the environment [8,9]. Traditional wastewater treatment facilities frequently lack the technology to properly catch microfibers, which can flow past filtering systems and into aquatic habitats. Advanced treatment technologies, such as membrane bioreactors (MBRs) and microfiltration, have showed promise for dramatically lowering microfiber emissions [10]. Moreover, the production of biodegradable textiles is a viable approach to reduce microfiber pollution. Research into natural fibers and bio-based synthetic fibers, such as polylactic acid (PLA) and other biopolymers, may lead to the development of textiles that degrade more easily in the environment [11]. Additionally, tighter weaves and novel textile designs can reduce fiber loss while washing and wearing. Brands can also spend in R&D to manufacture more durable fabrics, lowering the possibility of microfiber shedding [12].

ISO 4484-2:2023 [1] specifies a thorough technique for qualitatively and quantitatively assessing microplastics emitted by the textile industry into diverse matrices such as wastewater, air emissions, and solid waste. The standard uses molecular spectroscopy techniques such as Micro-FTIR and Micro-Raman to determine particle number, morphology, dimensional distribution, and polymer type, which provides critical information for ecotoxicological assessments and allows for comparisons across different textile processes and life cycle stages of textile products. The standard specifies particular techniques for sample preparation, purification, and analysis, taking into consideration the matrix' various physical states and possible contaminants, ensuring a full assessment of microplastic presence in the textile industry.

The aim of this study is to quantify the release of microfibers (MFs) from various stages of textile dyeing operations at an Italian company, and to assess the effectiveness of the existing wastewater treatment system in capturing these fibers. By applying the ISO 4484-2 standard, the study seeks to identify key stages contributing to MF emissions and to provide insights into potential improvements for reducing environmental impact.

2. EXPERIMENTAL STUDY

2.1. Materials

This study examines the amount of MFs released by an Italian dyeing company during each operation (Figure 1), encompassing underground water used in the process, inflow and outflow wastewater, and sludge. Wastewater samples were obtained from a textile dyeing company located in north of Italy that dyes 4 tons of yarn daily, both natural and synthetic materials. 1 L of wastewater samples collected from each stage. In order to prevent contamination, the bottles and all other equipment used were sterilized with distilled water and ethanol, and the samples provided were kept in the refrigerator.

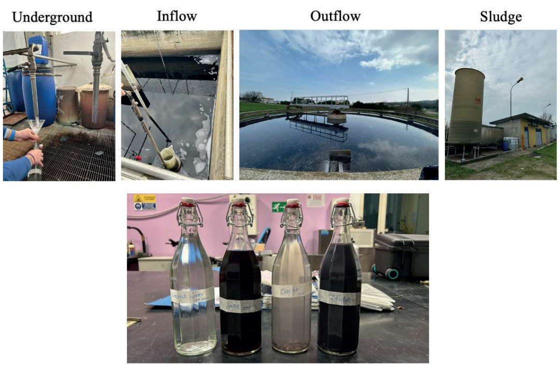

Figure 1. Wastewater samples were taken from different stages.

2.2. Methods

2.2.1 Pretreatment and Filtration of Wastewater

According to ISO 4484-2 standard [1], 15% hydrogen peroxide (Sigma-Aldrich) was used to pretreat the 200 mL of each wastewater samples treated with 15% H_2O_2 for 7 days at room temperature. After pretreatment, the filtration process was done with a 0.2 µm pore-size aluminum oxide (Anodisc, Whatman, Ø 47 mm) filter, then dried overnight at room temperature inside petri dishes.

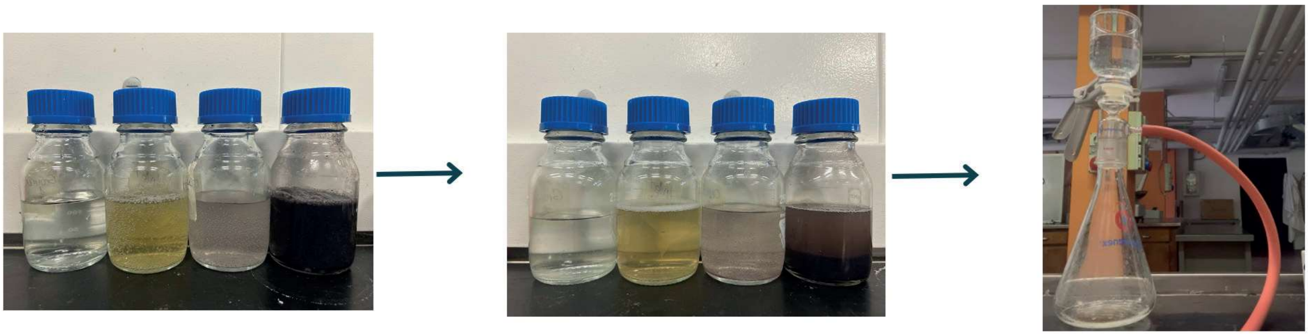

Figure 2. Pretreatment and filtration process for separation of MFs.

2.2.2 Analysis of Microfibers

With a UV flashlight (Alonefire SV10 365 nm UV torch 5W) mounted on a laboratory platform with a clamp, at an angle of 45 degrees, and at a fixed distance, filters were photographed using a high-definition SL.R camera (Sony ILCE-7RM3 v.1.01) equipped with a Zeiss 100 mm macro-1:2. For filters images were taken with an exposure of -2, 200 ISO, an exposure time of 0.62 s, and diaphragm apertures of f9 and f8, respectively. Image J program was used to count and measure the length of microfibers.

40 microfibers were characterized from the wastewater at each stage using a Shimadzu AIM-9000 Micro-FTIR at 700–4000 cm^{-1} and the library of spectra used was Shimadzu-T-Polymer2.

3. RESULTS

Images of the MFs can be seen in Figure 3, and the amount of microfiber released from each sample is given in Table 1. The results of counting of microfibers showed 250 MFs/L for underground water, 810 MFs/L for inflow wastewater, 520 MFs/L for outflow wastewater, 440 MFs/L for sludge. In sludge sample only 50 mL of sample can be analyzed because of organic and inorganic matter inside sample. The calculation of the wastewater treatment plant's efficiency based on the inflow and outflow microfiber amounts revealed a value of 35.8%. The literature supports the removal of 35%–59% of microplastics via WWTP during the preliminary phase [13].

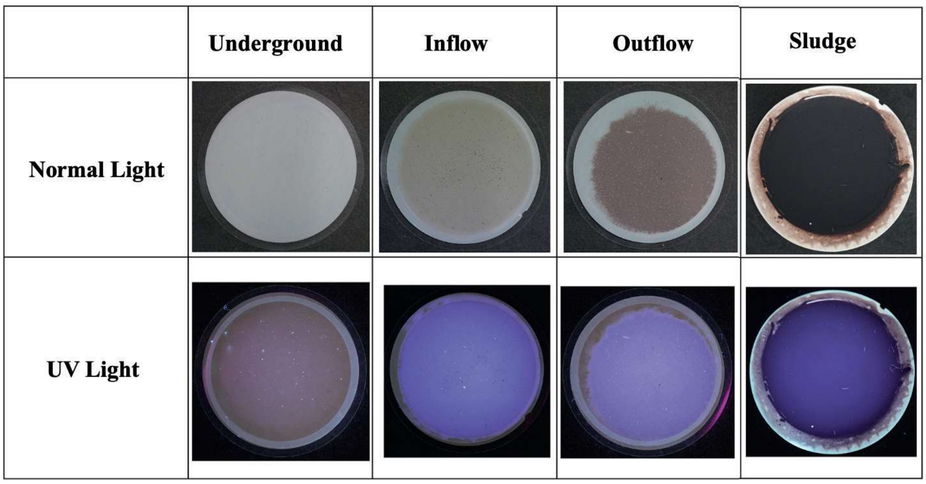

Figure 3. Images of filters.

Table 1. The amount of microfiber released from each stage.

	Underground	Inflow	Outflow	Sludge (50 mL)
Total amount of microfiber in 200 mL	50	162	104	22
MFs/L	250	810	520	440

In the inflow, outflow, and sludge samples, only microfibers were detected. However, in the underground water sample, microfibers, pellets, and fragments were all present. Of all the microparticles detected, 94% were microfibers, followed by 4% pellets and 2% fragments (Figure 4).

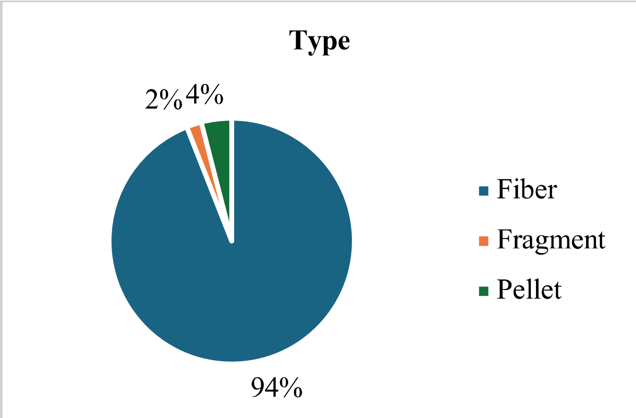

Figure 4. Type of microplastics for underground water.

MFs/MPs from all samples were measured individually, with fiber lengths ranging from 100 µm to 4 mm (Figure 5). In the underground water sample, 60% of the microplastics were shorter than 0.5 mm, followed by 24% with lengths between 0.5 mm and 1 mm. No microfibers longer than 2 mm were detected in this sample. For the inflow (63%), outflow (52%), and sludge (33%) samples, the majority of the fibers had lengths between 0.5 mm and 1 mm, followed by those shorter than 0.5 mm.

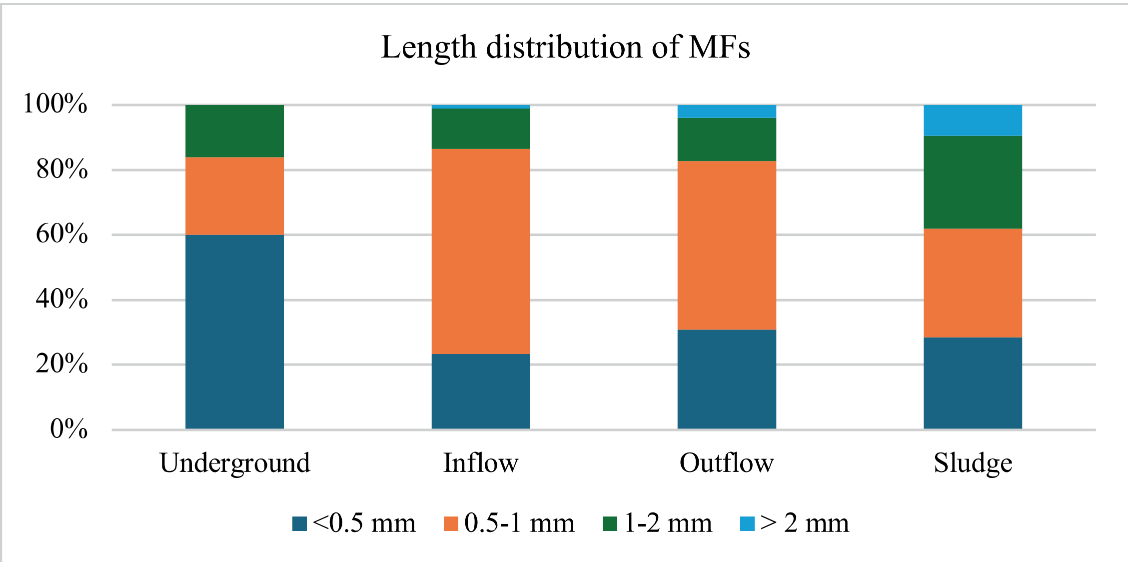

Figure 5. The length distribution of MFs/MPs

Figures 6 and 7 show the different colors and fluorescence of the collected microplastics/microfibers. As seen in Figure 6, most of the particles were transparent, followed by black and white. In Figure 7, most of the particles exhibited blue fluorescence, followed by those with no color.

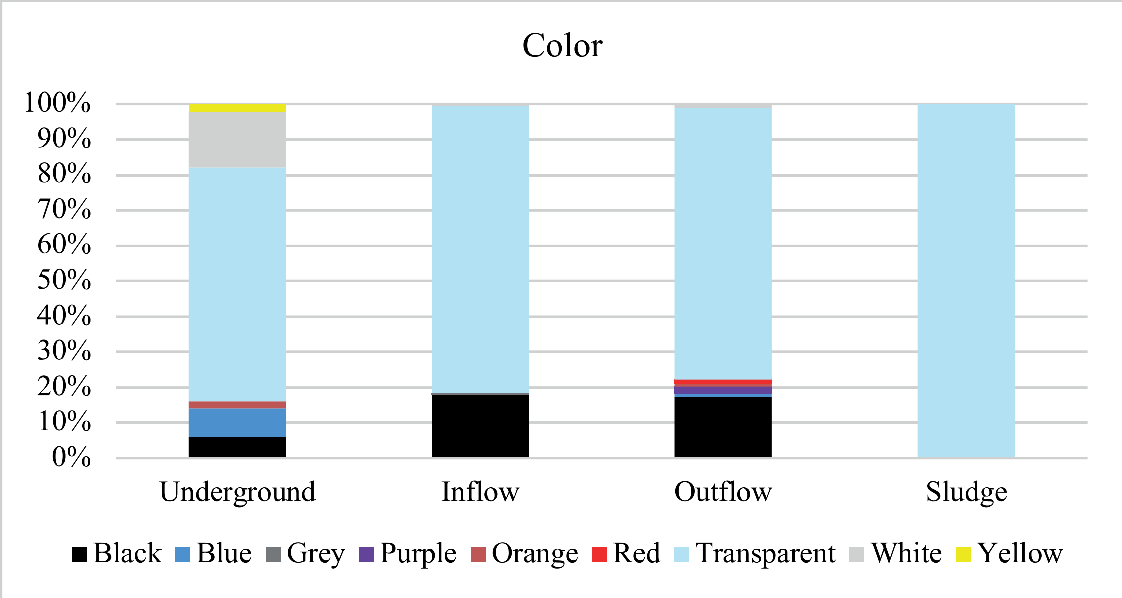

Figure 6. The color distribution of MFs/MPs

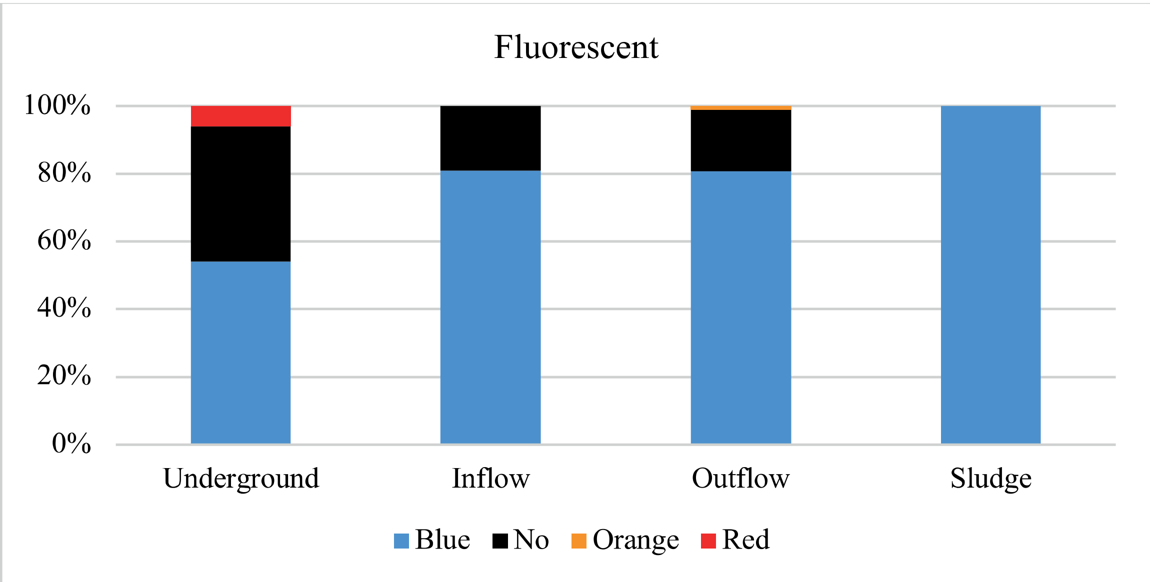

Figure 7. The fluorescent color distribution of MFs/MPs

Figure 9 shows the material distribution. Cotton, rayon, and polyester were detected in all samples, which is expected since cotton and polyester are the most used materials in the textile industry. In the underground water sample, PVC and polystyrene were also found.

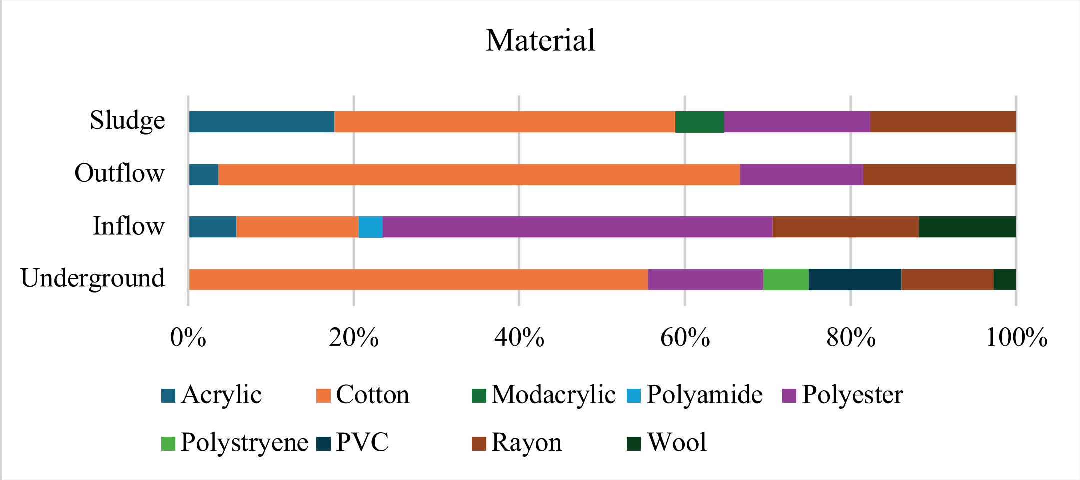

Figure 9. The material distribution of MFs/MPs

4. CONCLUSION

This study provides a comprehensive assessment of microfiber (MF) pollution from an Italian textile dyeing company, highlighting the significant environmental risks associated with microfiber release during various stages of textile production. The analysis, conducted in accordance with the ISO 4484-2 standard, revealed that microfibers were detected across all samples, with fiber lengths ranging from 100 µm to 4 mm. The majority of microfibers were found in the inflow and outflow wastewater samples, with a removal efficiency of only 35.8%, underscoring the need for improved wastewater treatment processes. Additionally, the detection of other microplastics, such as PVC and polystyrene, in the underground water sample suggests potential contamination pathways. Given the widespread use of cotton and polyester in the textile industry, the detection of these materials across all samples was anticipated. In conclusion, this research emphasizes the urgent need for the textile industry to adopt more effective wastewater treatment technologies and sustainable practices to mitigate the release of microfibers and other microplastics into the environment. By addressing these challenges, the industry can significantly reduce its environmental footprint and contribute to the preservation of aquatic ecosystems.

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BIOGRAPHY

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