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Seasonal Assessment and Treatment of Microfiber Pollution in Pampa-Triveni Region of the Pampa River

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***Abstract* - Microfibers are emerging pollutants and a subset of microplastics that are increasingly raising concern due to their persistence in freshwater ecosystems. Synthetic textile-derived fibers are primarily released into rivers and streams through domestic activities such as laundry. This study focuses on the Pampa River stretch known as Pampa Triveni, which experiences significant seasonal anthropogenic pressure during the Sabarimala pilgrimage, leading to potential deterioration in water quality. The objective of this study is to quantify microfiber concentrations before, during, and after the pilgrimage season and to analyze associated variations in water quality parameters. Water samples were collected following standard protocols and subjected to filtration, density separation, microscopic examination, and FTIR analysis for polymer confirmation. Results indicated a significant seasonal variation in microfiber abundance, increasing from 27 to 43 fibers per litre in the pre-pilgrimage period to 127 fibers per litre during the pilgrimage season. A partial reduction was observed post-season. A combined sustainable filtration system achieved a maximum microfiber removal efficiency of 81 percent. The filter, developed using eco-friendly and low-cost materials, effectively reduced both the number and size of microfibers, making it a sustainable solution for improving freshwater quality.**

Keywords - ***microfiber pollution, microplastics, seasonal variation, water quality, sustainable filter.***

I. INTRODUCTION

Microfibers, a subset of microplastics, have emerged as a significant environmental concern due to their widespread presence and persistence in aquatic ecosystems. These microscopic fibrous particles, typically less than 5 mm in size, are predominantly released from synthetic textiles during washing processes and are transported into natural water bodies through domestic wastewater discharge, surface runoff, and atmospheric deposition. Due to their small size and resistance to degradation, microfibers can accumulate in freshwater systems and pose potential risks to aquatic organisms and overall water quality.

Rivers act as major pathways for the transport of microfibers from terrestrial sources to larger water bodies. The accumulation of microfibers can disrupt aquatic ecosystems by entering the food chain, raising concerns about environmental sustainability, human health, and water quality management.

Fig. 1. Pampa-Triveni Region

The Pampa River shown in Fig. 1, is an ecologically and culturally significant river that experiences intense seasonal human activity. In particular, the Pampa-Triveni region witnesses a massive influx of pilgrims during the Sabarimala pilgrimage season. This seasonal surge in population leads to increased anthropogenic activities such as bathing, washing of clothes, and improper waste disposal, which contribute significantly to the deterioration of water quality and the introduction of microfiber pollutants into the river system.

Despite growing global awareness of microplastic pollution, limited studies have focused on the seasonal variation of microfiber contamination in pilgrimage-affected river systems, especially in the Indian context. Understanding these variations is essential for identifying pollution sources and developing effective mitigation strategies.

In this context, the present study aims to assess the seasonal variation of microfiber pollution in the Pampa-Triveni region of the Pampa River. The study also evaluates the relationship between microfiber concentration and water quality parameters, and investigates the effectiveness of low-cost filtration techniques for microfiber removal.

II. LITERATURE REVIEW

A literature review provides a comprehensive understanding of existing research in a specific field, helping to identify key developments, methodologies, and research gaps. In recent years, microfiber pollution has emerged as a significant environmental concern due to its widespread presence in aquatic ecosystems and its potential ecological and health impacts. Microfibers, which are a dominant form of microplastics, are primarily generated from synthetic textiles during washing processes and are transported into natural water bodies through wastewater discharge.

Microfiber pollution mainly originates from domestic and industrial activities, particularly textile washing processes. Studies have shown that household laundry is one of the major contributors to microfiber release into wastewater systems. Dodson et al. (2020) reported that approximately 80% of microplastics found in beach sediments were fibers, linking their presence to washing machine effluents. Similarly, Eamrat et al. (2025) demonstrated that washing parameters such as machine type, agitation speed, and cycle duration significantly influence microfiber emissions. Abourich et al. (2024) quantified microfiber release during laundry processes and reported an average discharge of 4.62 mg/L, highlighting the magnitude of pollution generated at the household level.

Rivers play a crucial role in transporting microfibers from terrestrial sources to marine environments. Sandil et al. (2025) investigated microfiber contamination in the Tiber River and identified microfibers as the dominant form of microplastics. The study also highlighted atmospheric deposition as an additional pathway contributing to microfiber pollution. These findings indicate that river systems act as both sinks and transport pathways.

Seasonal variations significantly influence the concentration and distribution of microfibers in aquatic systems. Tserendorj et al. (2024) reported an increase in microfiber emissions from wastewater treatment plants, with levels rising from 0.44 to 0.69 billion fibers per day between February and April. Such variations are attributed to changes in hydrological conditions, rainfall patterns, and human activities. These observations highlight the importance of seasonal assessments in understanding pollution dynamics.

Microfiber pollution also poses significant risks to environmental and human health. Rossi et al. (2025) identified the formation of a “plastisphere,” a microbial biofilm associated with microfibers that can harbor pathogenic organisms. Additionally, Ladewig et al. (2024) reported that microfiber accumulation negatively impacts benthic ecosystems by reducing organic matter degradation. These studies indicate that microfiber pollution affects both ecological balance and water quality. Accurate detection and characterization of microfibers require advanced analytical techniques. Methods such as Fourier Transform Infrared (FTIR) spectroscopy, Raman spectroscopy, microscopy, and density separation are widely used to identify fiber composition and quantify pollution levels.

Several treatment and mitigation strategies have been developed to control microfiber pollution. Wolff et al. (2021) demonstrated that sand filtration systems in wastewater treatment plants can achieve removal efficiencies of up to 99–99.9%. Similarly, Ateşci and İnan (2023) reported that powdered activated carbon is effective in removing fine particles through adsorption. However, Haque et al. (2024) observed inconsistent removal efficiencies (23.52%–82.19%) in textile effluent treatment plants, indicating limitations in existing systems. Furthermore, Abourich et al. (2024) highlighted challenges in adopting washing machine filters despite their effectiveness.

Despite significant advancements in microfiber research, several gaps remain. There is limited research focusing on microfiber pollution in the Pampa-Triveni region. Seasonal variation studies, particularly in relation to large-scale human activities such as pilgrimage, are scarce. Additionally, the relationship between microfiber load and specific anthropogenic activities has not been clearly quantified. The effectiveness of combined mesh and sand filtration systems has not been extensively evaluated, and previous studies lack detailed fiber identification using advanced analytical techniques. These gaps highlight the need for the present study.

III. METHODOLOGY

Fig. 2 illustrates the overall methodology adopted for the study. Initially, the Pampa-Triveni region was selected as the study area, and three sampling stations were identified along the river stretch based on the intensity of anthropogenic activities. Water samples were collected from all stations during the pre-pilgrimage, peak pilgrimage, and post-pilgrimage phases to evaluate seasonal variations in microfiber contamination.

The collected samples were transported to the laboratory for microfiber extraction and characterization. Organic matter present in the samples was removed through chemical treatment, followed by filtration and microscopic examination for the identification and quantification of microfiber particles. Selected samples were further analyzed using spectroscopic techniques to determine polymer composition.

In addition to microfiber analysis, important water quality parameters such as pH, turbidity, and electrical conductivity were evaluated according to standard procedures. A laboratory-scale multilayer filtration system consisting of gravel, sand, activated charcoal, and mesh filters was then designed and tested to assess microfiber removal efficiency. The obtained results were analyzed to determine seasonal pollution trends and the effectiveness of the proposed treatment system.

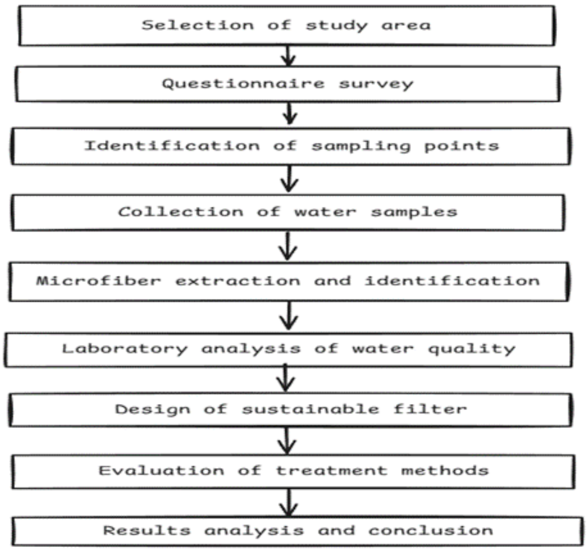


Fig. 2. Flow Chart

A. *Study Area Selection*

Fig. 3. Location of Sampling Points

The study was conducted in the Pampa-Triveni region in Pathanamthitta District, Kerala along a 1-km stretch from the upper Triveni bathing ghat to the downstream section. Three sampling stations were taken: Station S1 which was upstream at 9°24′48.1″N, 77°04′11.6″E, Station S2 which was midstream at 9°24′57.9″N, 77°03′35.6″E, and Station S3 which was downstream at 9°24′57.6″N, 77°04′00.2″E as shown in Fig. 3. GPS mapping and photographic documentation were used to ensure accuracy.

B. Sample Collection

Water samples were collected during three phases: pre-pilgrimage (baseline), peak pilgrimage, and post-pilgrimage periods. Sampling was conducted at all three stations using pre-cleaned high-density polyethylene (HDPE) bottles, which were submerged approximately 10–15 cm below the water surface to avoid surface contaminants.

All samples were immediately sealed with aluminium foil, properly labelled, and stored in dark, insulated containers to prevent external contamination and degradation.

The collected samples were transported to the laboratory and processed within 24 hours. To minimize contamination during sampling, personnel wore cotton clothing, and field blanks were maintained as quality control measures.

C. Microfiber Extraction and Identification

Collected water samples were transported to the laboratory for quantitative and qualitative analysis of microfibers. Initially, samples were treated with hydrogen peroxide to remove organic matter without affecting the integrity of synthetic fibers. Following digestion, the samples were subjected to sequential filtration and sieving using graded mesh filters to isolate microfiber particles. The retained particles were then carefully transferred onto filter papers for further examination.

Microscopic analysis was carried out to identify and enumerate microfibers based on their morphology, color, and texture. Microfiber concentration was expressed in terms of fibers per liter (fibers/L).

Selected samples were further analyzed using spectroscopic techniques to determine polymer composition. This analysis confirmed the presence of synthetic materials such as polyester, nylon, acrylic, and polypropylene, enabling source identification of the microfibers.

D. Water Quality Analysis

Three parameters were analyzed as per IS 3025 standards, namely turbidity according to IS 3025 Part 10 1984 with a permissible limit of 1 to 5 NTU, electrical conductivity according to IS 3025 Part 14 1984 with a limit of up to 600 micro siemens per centimeter, and pH according to IS 3025 Part 11 1983 with an acceptable range of 6.5 to 8.5.

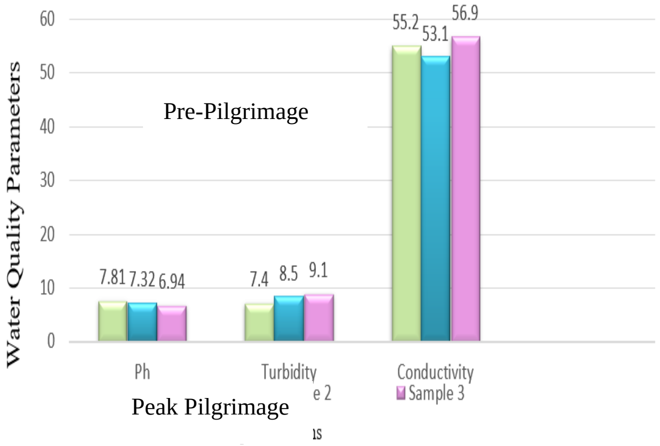
E. Filtration System Design and Evaluation

A sustainable filtration unit was constructed comprising from bottom to top: coarse gravel of 8 cm, river sand of 8 cm, activated charcoal of 8 cm, and a nylon mesh filter. Microfiber-contaminated water was passed through the column under gravity. Removal efficiency was calculated as:

$$\textbf{Efficiency (\%)} = [(C_{in} - C_{out}) / C_{in}] \times 100$$

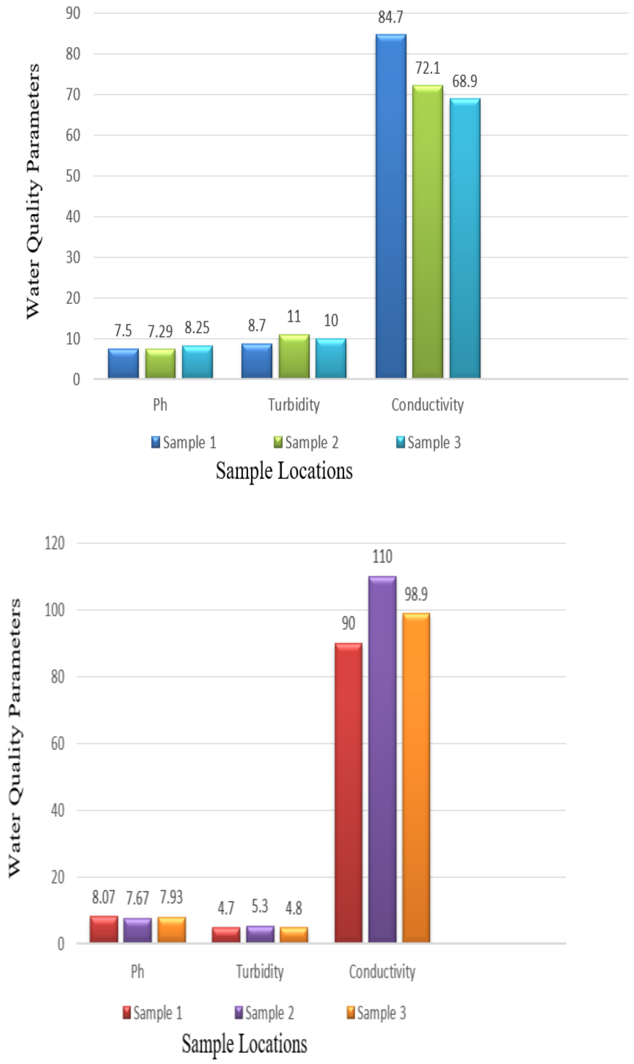
where C_{in} is the influent microfiber concentration and C_{out} is the effluent concentration.

IV. RESULTS AND DISCUSSION



Pre-Pilgrimage

Peak Pilgrimage



A. Water Quality Parameters

Fig. 4. Water Quality Parameters

pH values remained within the permissible range of 6.5-8.5 across all seasons, as shown in Fig. 4, confirming chemical stability. However, turbidity values (7.4-11.0 NTU) consistently exceeded the 5 NTU permissible limit during and before the pilgrimage, indicating significant suspended particle loads. Conductivity values (53.1-110 µS /cm) were elevated, particularly post-pilgrimage at Station S2 (110 µS/cm), suggesting accumulation of dissolved ionic pollutants from human activities.

B. Microfiber Abundance and Seasonal Variation

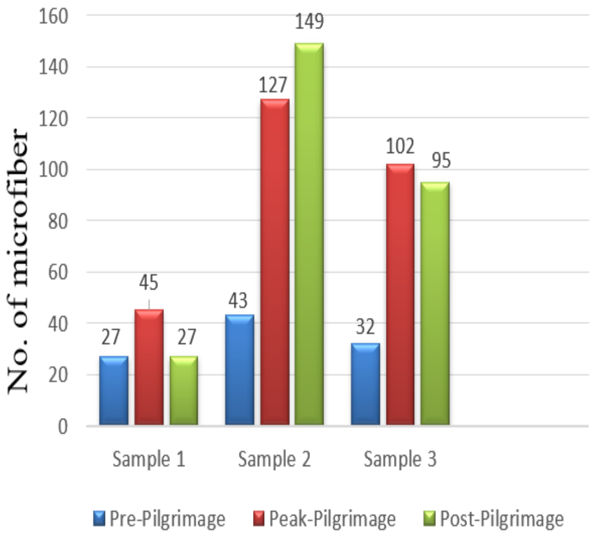


Fig. 5. Microfiber Abundance

Microfiber contamination showed a clear seasonal pattern as illustrated in Fig. 5. Pre-pilgrimage concentrations ranged from 27–43 fibers/L, representing baseline conditions. During the peak pilgrimage period, levels increased significantly, reaching up to 127 fibers/L due to intensified human activities such as bathing and washing.

Post-pilgrimage values remained elevated, with a maximum of 149 fibers/L, indicating resuspension and continued transport of fibers within the river system. The midstream station recorded the highest concentrations, while the upstream station showed comparatively lower levels.

C. Microfiber Characterization

1) Color Distribution

Pre-pilgrimage samples were dominated by blue fibers, indicative of common synthetic textile sources. During the pilgrimage season, black fibers became dominant, as shown in Fig. 6, comprising approximately 50-60% of total fibers at Stations S2 and S3. Post-pilgrimage, black fibers remained dominant at midstream and downstream stations (62-69 fibers), confirming persistent contamination from pilgrimage-specific sources.

Fig. 6. Black Fiber Viewed Under Microscope

2) Size Distribution

TABLE I. Microfiber Size Range Summary

Season	Sample	No. of Fibers	Size Range (µm)
Pre-Pilgrimage	S1	27	98.95 – 3024.9
	S2	43	114.89 – 4294.3
	S3	32	127.53 – 3516.4
Peak Pilgrimage	S1	45	82.01 – 2978.3
	S2	127	162.14 – 6164.75
	S3	102	21.28 – 4263.66
Post-Pilgrimage	S1	27	23.22 – 1124.35
	S2	149	30.63 – 986.82
	S3	95	65.5 – 3817.6

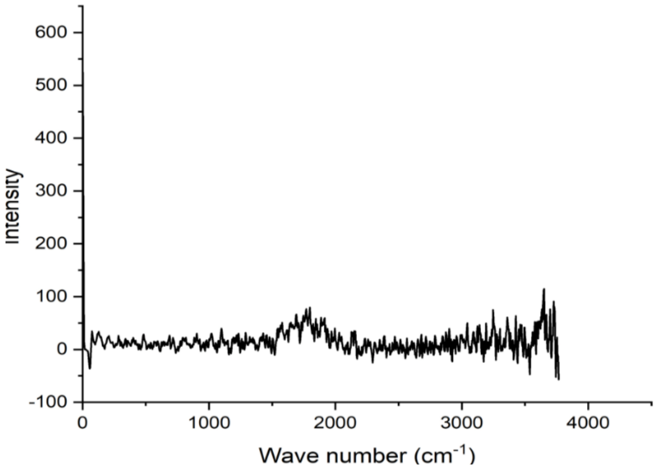
Table I summarizes the seasonal variation in microfiber abundance and size distribution across the sampling stations. The highest contamination was observed during the peak and post-pilgrimage phases, with the maximum concentration recorded at Station S2 during the post-pilgrimage period (149 fibers/L). Elevated microfiber levels at Stations S2 and S3 indicate the strong influence of anthropogenic activities within the study area.

The widest size range was observed at Peak Pilgrimage S2 (162.14–6164.75 µm), whereas the post-pilgrimage S2 sample (30.63–986.82 µm) exhibited a comparatively narrower range. This suggests gradual deposition of larger fibers and continued suspension of finer particles within the river system.

D. Polymer Identification by Raman Spectroscopy

TABLE II. Polymer Types Identified by Raman Spectroscopy

Season	Polymer Identified	Key Spectral Feature
Pre-Pilgrimage	Polypropylene (PP)	C-H stretch 2800-3000 cm⁻¹
	Polyethylene (PE)	Sharp CH_2 stretch ~2900 cm⁻¹
	Polyvinyl Chloride (PVC)	C-C, C-H peaks 1000-1700 cm⁻¹
Peak Pilgrimage	Polypropylene (PP)	C-H bending at 1450, 1375 cm⁻¹
	Polyethylene (PE)	Aliphatic C-H at 2800-3000 cm⁻¹
	Polysulfone (PSU)	Aromatic ring ~1500-1600 cm⁻¹; SO_2 group ~1100-1300 cm⁻¹
Post-Pilgrimage	Polydienes	C=C stretch 1600-1650 cm⁻¹
	LDPE	C-H stretch 2850-2950 cm⁻¹; CH_2 rock ~720 cm⁻¹
	Polyethylene (PE)	Saturated hydrocarbon chain ($-CH_2-$)



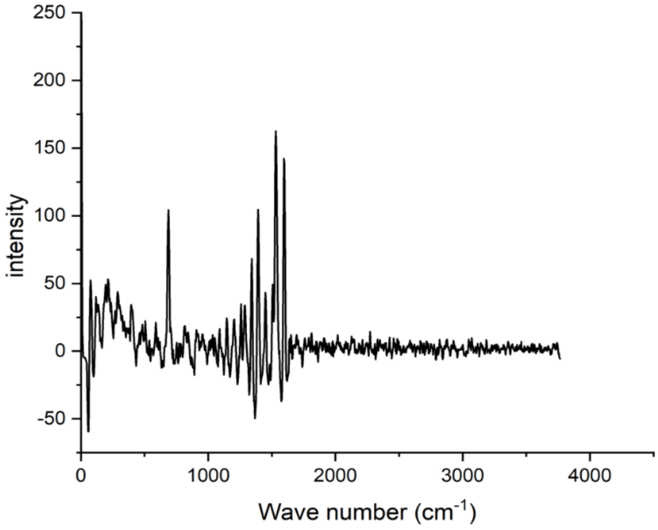


Fig. 7. Polysulfones

Fig. 8. Polydienes

As shown in Fig. 7, the detection of polysulfone during peak pilgrimage season is significant, as this engineering polymer is typically associated with industrial membrane filters and medical devices, suggesting potential non-textile sources given in Table II. As shown in Fig. 8, the presence of polydienes in the post-pilgrimage samples may be associated with tire wear particles transported into the river through surface runoff from increased vehicular activity.

E. Performance of Sustainable Filtration Method

The laboratory-scale multilayer filtration system shown in Fig. 9 was evaluated using the highly contaminated post-pilgrimage sample collected from Station S2 (149 fibers/L). Following treatment, the microfiber concentration decreased to 28 fibers/L, resulting in a removal efficiency of 81%.

$$\text{Efficiency (\%)} = \frac{149 - 28}{149} \times 100 \approx 81\%$$

Post-treatment analysis showed a reduction in fiber size range from 162–6165 µm to 162–518 µm, indicating effective removal of medium-sized fibers by the sand and mesh layers. However, the persistence of smaller-sized fibers in the treated sample indicates limitations in the removal of fine microfibers. This highlights the need for additional treatment methods such as powdered activated carbon (PAC) adsorption or membrane filtration for improved removal efficiency.

Fig. 9. Sustainable Filter

V. CONCLUSION

This study presents a comprehensive seasonal assessment of microfiber pollution in the Pampa-Triveni region of the Pampa River. The findings clearly demonstrate a strong correlation between human activities and microfiber contamination levels.

A distinct three-phase seasonal pattern was observed, with baseline concentrations (27–43 fibers/L) increasing significantly to a peak of 127 fibers/L during the Sabarimala pilgrimage, followed by only partial recovery post-season (up to 149 fibers/L), indicating persistent environmental contamination.

The transition from predominantly blue fibers in the pre-pilgrimage phase to black fibers during the pilgrimage season highlights the direct influence of synthetic pilgrim garments as a major pollution source. Polymer characterization further confirmed the presence of materials such as polypropylene, polyethylene, PVC, PET, and other synthetic compounds, indicating multiple anthropogenic sources including textiles, industrial inputs, and vehicular runoff.

The developed mesh and sand filtration system demonstrated a removal efficiency of approximately 81%, indicating its potential as a cost-effective and decentralized treatment solution for microfiber pollution in high-impact zones.

The study also identifies a significant gap between environmental awareness and actual practices among users, emphasizing the need for targeted awareness programs and policy-level interventions. Future research should focus on the removal of finer microfibers, sediment accumulation, and long-term ecological and health impacts.

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REFERENCES

[1] E. Allen, J. Wood, C.E. Henninger, A. Gallego-Schmid, E. Asuquo, A. Garforth, and D.J. Lewis, "Microfibre and nanofibre: pollution and environmental impacts," Procedia CIRP, vol. 135, pp. 384-387, 2025.

[2] M. Sheikhi, C. Bianco, A. Tiraferri, and R. Sethi, "Evaluating microfiber emissions and point-of-use filtration efficiency in household washing and drying cycles," Journal of Hazardous Materials, vol. 489, Article 137646, 2025.

[3] E. Allen, C.E. Henninger, C. Jones, J. Wood, and A. Garforth, "Fibre fragment pollution: source directed intervention through design," The Journal of The Textile Institute, vol. 116, no. 7, pp. 1451-1462, 2025.

[4] S.R. Balasaraswathi and R. Rathinamoorthy, "Microfiber release during apparel manufacturing process - A greater concern than domestic laundering," Emerging Contaminants, vol. 11, Article 100412, 2025.

[5] M. Sotiropoulou, A. Stefanatou, S. Schiza, and I. Petousi, "Removal of microfiber in vertical flow constructed wetlands treating greywater," Science of the Total Environment, vol. 858, pp. 159723, 2023.

[6] S. Wolff, F. Weber, J. Kerpen, M. Winklhofer, C. Engelhard, and J.W. Metzger, "Elimination of microplastics by downstream sand filters in wastewater treatment," Water, vol. 13, no. 1, pp. 33, 2021.

[7] Z.C. Atesci and H. Inan, "Removal of microfiber and surfactants from household laundry washing effluents by powdered activated carbon: kinetics and isotherm studies," Water Science and Technology, vol. 88, no. 1, pp. 164-182, 2023.

[8] M.N. Woods, T.J. Hong, D. Baughman, G. Andrews, S. Madaras, and S.M. Brander, "Accumulation and effects of microplastic fibers in American lobster larvae," Marine Pollution Bulletin, vol. 160, Article 111691, 2020.

[9] M. Rossi et al., "Microplastics, microfibers and associated microbiota biofilm analysis in seawater, a case study from the Vesuvian Coast, southern Italy," Journal of Hazardous Materials, vol. 481, Article 136512, 2025.

[10] S.M. Ladewig et al., "Polyester microfiber impacts on coastal sediment organic matter consumption," Marine Pollution Bulletin, vol. 202, Article 116298, 2024.

[11] S. Sandil, D. Tserendorj, A. Karoly, and F. Spagnoli, "Microplastic and microfiber contamination in the Tiber River, Italy," Marine Pollution Bulletin, vol. 210, Article 117364, 2025.

[12] G.Z. Dodson, A.K. Shotorban, P.G. Hatcher, A.L. Noffke, and S.A. Bridges, "Microplastic fragment and fiber contamination of beach sediments," Marine Pollution Bulletin, vol. 151, Article 110869, 2020.

[13] M.M. Haque, A.T. Kabir, E.M. Latifi, and M.R. Hossain, "Microfiber prevalence and removal efficiency of textile effluent treatment plants in Bangladesh," Journal of Hazardous Materials Advances, vol. 14, Article 100418, 2024.

[14] M. Abourich, A. Bellamy, and A. Ajji, "Washing machine filters to mitigate microplastics release: Citizen science study," Environmental Challenges, vol. 15, Article 100863, 2024.

[15] M. Mancini et al., "Synthetic microfibers driven by turbidity currents," Marine Pollution Bulletin, vol. 210, Article 117329, 2025.

[16] R. Eamrat et al., "Unveiling microfiber emissions: A comprehensive analysis of household washing activities," Case Studies in Chemical and Environmental Engineering, vol. 11, Article 100868, 2025.

[17] D. Tserendorj, S. Sandil, M. Adany, Dobosy, and M. Zarandi, "Microfiber emission from a municipal wastewater treatment plant in Hungary," Scientific Reports, vol. 14, no. 1, Article 4265, 2024.

[18] J.P. Costa, A. Costa, and A. Marinho, "Quantification and identification of microfibers released from textiles during simulated accelerated washing," Green Analytical Chemistry, vol. 12, Article 100155, 2025.

[19] S.H. Akyildiz et al., "Comparison of methodologies for microfiber analysis across different stages of wastewater from a textile dyeing company," Journal of Hazardous Materials Advances, vol. 17, Article 100486, 2025.

[20] A.P. Periyasamy, "Evaluation of microfiber release from jeans: the impact of different washing conditions," Environmental Science and Pollution Research, vol. 28, no. 31, pp. 42216-42231, 2021.