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Microfiber Removal in Wastewater Treatment: A Stage-wise Analysis from Sri Lanka

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***Abstract*—Microfibers, a major category of microplastics, have been widely detected in aquatic environments worldwide, posing threats to the natural environment. Wastewater treatment plants (WWTPs) are considered a major sink and a source for microfibers. They are mainly found in the industrial wastewater derived primarily from textiles. However, in Sri Lanka, the understanding of the removal of microfibers in WWTPs is limited, and therefore, the development of effective microfiber remediation strategies has been constrained. To address this knowledge gap, this study aims to assess the microfiber abundance at major treatment stages of a WWTP and the stage-wise microfiber removal efficiency, highlighting the temporal variations over four consecutive sampling months. Sampling was conducted in a centralized industrial WWTP, in the Colombo District, Sri Lanka, from January to April 2025, at six sampling locations, including inlet, equalization tank, inlet and outlet of the oxidation ditch, settlement tank (secondary), and discharge point, covering major treatment stages of the WWTP. Microfibers were visually quantified using stereomicroscopy. Results indicated a progressive reduction in microfiber concentration across successive treatment stages with influent microfiber concentrations ranging from 29.11 ± 5.34 to 46.44 ± 11.47 microfibers/L. The secondary sedimentation tank demonstrated the highest removal achieving 78.5 %, serving as the major settling process of the WWTP, in the absence of primary settling tank. Microfiber concentration differed significantly across treatment stages (Kruskal-Wallis, $p = 0.003$) and was strongly negatively correlated with treatment stages (Spearman's $\rho = -0.843$). The final discharge point showed < 5 microfibers/L, highlighting an effective but incomplete removal. This study underscores the need for advanced treatment strategies for mitigating microfiber contamination in Sri Lankan wastewater treatment systems.**

Keywords—Industrial wastewater, microplastics, removal efficiency, wastewater treatment plant

I. Introduction

Microfibers, a major morphotype of microplastics, are increasingly being detected in industrial wastewater treatment plants (WWTPs) worldwide, calling attention to their distribution and potential discharge into water bodies [1], [2]. These fibers, mainly derived from synthetic textiles, often escape conventional wastewater treatment strategies due to their minute size and buoyant nature [3]. Microfibers are typically < 5 mm in size and include a mixture of polyester, nylon, acrylic, and polyethylene terephthalate fibers, which differ in chemical composition and surface properties, influencing their interactions with coexisting pollutants, organic matter, and microbial communities in WWTPs [4], [5]. Despite primary, secondary, and tertiary treatments of conventional WWTPs, microfibers are found in treated effluents, significantly contributing to environmental contamination. For example, a recent study reported a microfiber removal rate of 95.1%, reducing influent microfibers from 334.1 items/L to 16.3 items/L, while still releasing 4.89×10^8 microfibers into the receiving water every day [6]. Similarly, municipal WWTPs, even after 95-99% microfiber removal efficiency, emit around 160 million microfibers per day into the environment [7]. Such findings indicate that even highly efficient WWTPs are not fully capable of eliminating microfibers, particularly the smaller size fractions (< 250 μm) which are prone to escape sedimentation and filtration processes. Even with microplastic removal efficiencies exceeding 90 %, WWTPs may release millions of microplastics, especially microfibers, daily into the natural environment, posing severe threats to organisms [8]. Furthermore, a recent study revealed microfiber concentrations in the effluent from a WWTP with activated sludge, varying between 1.9-6.8 items/L, confirming the emission of microfibers into the environment, even in well-operated plants [9]. Another study emphasized the key gaps, especially in assessing fiber-shaped microplastics over time across treatment stages [10]. A case study in Denizli, Turkey, showed the daily discharge of microfibers was still significant (41.8-60.8%), although the overall microplastic removal of the WWTP exceeded 95% [11]. These global findings suggest that conventional treatment technologies, while efficient in general solids removal, are not specifically designed to target microfibers, highlighting the urgent need for advanced technologies such as membrane bioreactors, dissolved air flotation, or adsorption-based hybrid methods. In Sri Lanka, the knowledge of microfiber contamination in WWTPs is limited, especially at industrial facilities. Only a few studies have addressed microplastic contamination in coastal and freshwater environments, but none have systematically evaluated the microfiber dynamics in wastewater systems. Considering the well-established textile industry in Sri Lanka, the potential contribution of industrial effluents to microfiber pollution could be substantial. This study aims to fill this knowledge gap by exploring the stage-wise and temporal variation of microfibers in a centralized industrial WWTP located in Colombo District, Sri Lanka. Sampling was done at major treatment stages of the plant to assess the microfiber abundance and its temporal variations. The results of this study will provide valuable baseline data to understand the microfiber dynamics in a local WWTP and to establish targeted mitigation strategies to minimize environmental microfiber release.

II. METHODOLOGY

A. Study site and sampling

The study was conducted at a centralized industrial WWTP in the Colombo District, Sri Lanka. The WWTP receives wastewater from multiple industries, including textile, food and beverage, chemical, mineral processing, and rubber. These industries collectively contribute a complex mixture of pollutants, including synthetic microfibers, polymer additives, dyes, and trace metals, which may influence the behavior and fate of microplastics in the treatment system. The plant operates treatment processes such as equalization, biological treatment (oxidation ditch), sedimentation, and chlorination. The absence of a primary settling tank within the WWTP allows particulate matter, including microfibers and other microplastics, to enter directly into the biological treatment stage, potentially impacting both the hydraulic retention time and the efficiency of microbial degradation processes. The plant has a design treatment capacity of approximately 10,000 m^3/day, enabling it to accommodate a continuous and variable industrial water load.

Grab sampling was done at six sampling points, including raw influent (inlet), equalization tank, oxidation ditch inlet and outlet, settlement tank (secondary), and final discharge point, covering major treatment stages of the WWTP over a sampling period of four months from January to April 2025. To ensure representativeness, samples were collected at approximately the same time of day during each month, considering diurnal variations in industrial discharge rates. 5L samples were collected per sampling location, in triplicate. Collected samples were transported and stored at -4 °C for laboratory analysis.

B. Sample preparation and analysis

Collected wastewater samples were sieved to remove large debris. Inorganic matter was removed by the treatment with saturated NaCl and left for 24 h to allow density separation. After 24 h, the top layer of the solution was filtered using Whatman grade 2 filter papers (pore size: 8 µm). Filter papers with retained particles were then dried at 80 °C before further analysis. The dried particles were examined using a stereomicroscope (OPTIKA – OPTIKAM B9 – 4083.B9) at x40 magnification to observe their morphology and to visually quantify them for physical characterization of microplastics.

C. Quality assurance and quality control

Quality assurance and control steps were implemented to prevent contamination of samples. All laboratory glassware was rinsed thoroughly prior to use. Cotton laboratory coats and nitrile gloves were worn during the analysis. Samples and materials were covered using aluminum foil until use. Materials and containers that are made of plastic were avoided to the greatest extent possible. In the laboratory, samples were stored in glass containers and processed under a laminar flow hood to further minimize contamination. The sampling containers were rinsed three times with filtered deionized water before each collection. Air blank samples were used to monitor airborne microplastic contamination during the laboratory analysis. Deionized water exposed to the air during sampling was collected as field blanks to account for airborne microplastic contamination.

D. Calculations

Microfiber concentration was calculated for each treatment stage per month and was expressed as microfibers per liter ± Standard Deviation (SD).

Stage-wise removal efficiency (%) was calculated using the following formula:

$$Removal\ Efficiency\ (\%) = \frac{(Concentration\ influent\ - Concentration\ effluent)}{Concentration\ influent} \times\ 100$$

E. Statistical analysis

Statistical analysis was performed using Minitab 17. The normality of microfiber concentration data was assessed using the Anderson-Darling test. Data showed deviations from normality ($p < 0.05$), and thereby nonparametric statistical tests were performed. The Kruskal-Wallis H test was employed to assess the difference in microfiber concentration among the six sampling locations. Spearman's rank correlation coefficient (ρ) was employed to evaluate the relationship between the microfiber concentration and sampling locations. All tests were performed with a significance level of $\alpha = 0.05$.

III. DISCUSSION AND CONCLUSION

Results indicate a clear reduction of microfibers across different treatment stages of the WWTP, from the inlet to the final discharge point, in all sampling months (Figure 1), demonstrating the effectiveness of the wastewater treatment of the plant. Influent microfiber concentration ranges from 29.11 ± 5.34 to 46.44 ± 11.47 microfibers/L, showing substantial amounts of microfibers in the wastewater influent. The settlement tank shows a drastic reduction in microfibers (to 3.77-8.22 microfibers/L) compared to the other treatment stages, in all the sampling months. The final discharge point, where the treated water is discharged into the environment, reported the minimum microfiber concentration (< 5 microfibers/L), highlighting both the effectiveness of the treatment process as well as the incomplete removal of microfibers.

Temporal variations indicate a notable increase in microfibers in March. This may be attributed to the slowing down of factory production towards the end of the year due to scheduled shutdowns or reduced operations, resulting in a low microfiber influent load in the early months of the following year. By March, industrial activity reaches its optimum level, releasing substantial microfibers into wastewater. These findings support the hypothesis that temporal fluctuations, especially driven by production cycles, are important determinants of microfiber load entering WWTPs. Accounting for these patterns is essential when designing monitoring schedules, interpreting treatment efficiency, and estimating environmental discharge of microplastics.

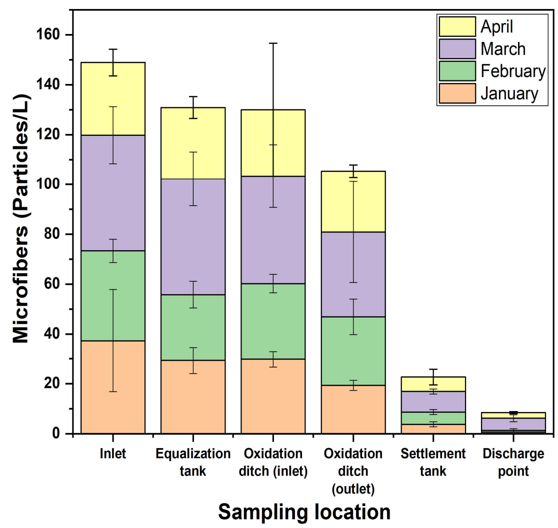

Figure 1. Monthly variation of microfiber abundance across different treatment stages from January to April 2025. Sampling points include the inlet, the equalization tank, the oxidation ditch inlet and outlet, the settlement tank, and the final discharge point.

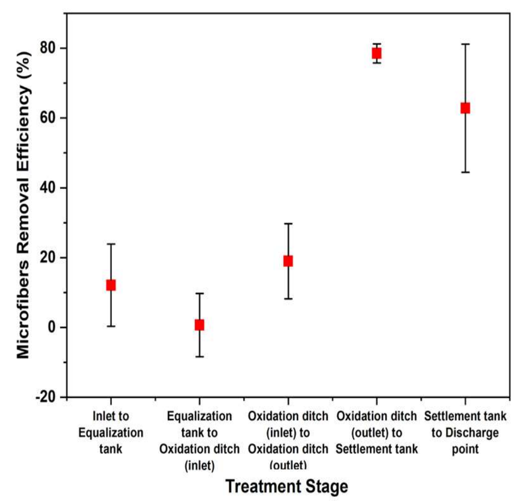

Figure 2. Microfiber removal efficiency across various treatment stages of the plant from January to April 2025. The settlement tank (secondary) shows the highest microfiber removal efficiency.

Microfiber removal efficiencies in the WWTP show a notable variation across various treatment stages from January to April 2025 (Figure 2). Furthermore, some treatment processes show a high contribution to the microfiber reduction. Early treatment stages, such as the inlet and the equalization tank, demonstrate a low removal efficiency, probably because these preliminary treatment stages contribute mostly to the homogenization of wastewater rather than removing microfibers physically. A moderate microfiber removal was shown from the oxidation ditch inlet to the outlet (18.97 %), suggesting the settlement of heavier fibers and microbial flocculation within the biological treatment process [12], [13]. The highest microfiber removal efficiency (78.5 %) was shown at the settlement tank (secondary), contributing substantially to the reduction of microfibers in wastewater. Since this WWTP lacks primary settling tanks, it is reasonable that the secondary settlement tank shows the highest microfiber removal. The presence of microfibers in the final discharge point demonstrates the inefficiency of the plant for the complete removal of microfibers, which aligns with many global study findings [12], [14]. This finding suggests the establishment of advanced and targeted microfiber removal techniques in the Sri Lankan wastewater treatment system.

According to the results of the statistical analysis, Kruskal-Wallis revealed a statistically significant difference between the microfiber concentration and the six sampling locations ($H = 17.88$, $df = 5$, $p = 0.003$). This shows that the microfiber concentration significantly differs among the treatment stages of the WWTP. The Spearman's rank correlation coefficient (ρ) resulted in – 0.843, indicating a strong negative correlation between the microfiber concentration and the treatment stages. This shows the reduction of microfiber concentration along the consecutive treatment stages of the WWTP.

The study highlights the effectiveness of the WWTP in the removal of microfibers across the successive treatment stages, with the highest removal at the settlement tank (secondary). The difference in the microfiber concentration across successive treatment stages and the negative correlation between them underscore the progressive reduction of microfibers in the WWTP. Despite the effective wastewater treatment in the plant, the final effluent is shown to be still contaminated with microfibers, necessitating the need for advanced and effective removal techniques in the Sri Lankan wastewater treatment systems. In addition to technological upgrades, the findings highlight the importance of establishing robust regulatory frameworks and monitoring guidelines to address microfiber pollution. Developing effluent discharge standards specific to microplastics, enforcing compliance through regulatory agencies and promoting industry -academia collaborations will be crucial steps toward minimizing environmental releases. Furthermore, optimizing plant operational parameters and strengthening sludge management practices could provide additional avenues to reduce microfiber dispersal through both effluent and biosolids.

Overall, this study provides the first baseline evidence of microfiber dynamics in an industrial WWTP in Sri Lanka, offering critical insights into stage-wise behavior and removal performance. The outcomes contribute to the growing body of global knowledge on microfiber pollution, while also serving as a foundation for national strategies aimed at mitigating microfiber emissions. Future studies should expand on this work by assessing seasonal variations, polymer-specific behaviors, and ecological risks of microfiber-contaminated effluents, thereby supporting the development of targeted, science-based policies for sustainable wastewater management.

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