# Characterization of Microplastics in Wastewater Treatment Plants and Filtration Using a Sand-Char Model

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**Table:** 09

**Figure:** 07

**Keywords:** Microplastics (MPs), Water Treatment Plant (WTP), Sewage Treatment Plant (STP), Stereomicroscopy, Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), Low-cost Filtration, Sand-Char Filter

## Abstract:-

The current study focused on detecting and removing microplastics (MPs) from wastewater using a low-cost filter. Microplastics are very small plastic pieces that pollute water and can harm both animals and people. For this study, water samples were collected from three treatment plants in Srinagar: Hariparbat STP, Laam STP, and Nishat WTP. The presence of microplastics was studied under stereo microscope, FTIR (Fourier Transform Infrared Spectroscopy), and SEM (Scanning Electron Microscopy). Common microplastic shapes found were cross-network microfibres, fibres, films, fragments, and foams. Hariparbat STP had the highest number of microplastics, followed by Laam STP and then Nishat WTP. Biological treatment was most effective in removing microplastics (91.93%), followed by chemical (65.10%) and physical stage (41.05%) in STPs; however, in WTP, maximum removal efficiency was shown by Physical Stage (69.28%) followed by chemical stage (49.62%). As Nishat WTP does not have a biological stage, it showed lower removal. The main microplastic polymers found were PET, PP, PE, PVC, LDPE, HDPE and PAN. Overall removal efficiency was highest in Hariparbat STP (99.7%), followed by Laam STP (97.66%) and Nishat WTP (84.52%). For removal, a low-cost filter was developed using sand, charcoal, and activated charcoal in different combinations. Among all filters tested, the sand-activated charcoal filter showed the highest removal efficiency (99.5%), followed by the sand-charcoal filter (99%) and the plain sand filter (97.16%). The sand-charcoal filter was the most affordable and effective for wider use in low-resource areas.

**Key words:** Microplastics (MPs), Water Treatment Plant (WTP), Sewage Treatment Plant (STP), Stereomicroscopy, Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), Low-cost Filtration, Sand-Char Filter

## 1. Introduction

In 2021, approximately 394 metric tons of plastic products were manufactured worldwide. The production of plastics reached a staggering 400.3 million metric tons in 2022. Every year, approximately 8 million metric tons of plastic debris enter the ocean environment, and projections suggest this figure could quadruple by the year 2050 (Derraik, 2002). With the continuous growth in global plastic production, the presence of microplastics (MPs) within water bodies has also been steadily rising. At present, around 71% of plastic waste ends up being released directly into natural ecosystems, while the rest is processed and repurposed in various ways, further contributing to the increasing levels of microplastic contamination. Plastics degrade slowly in the water ecosystem, resulting in the formation of microplastics (MPs) and nanoplastics (NPs).

A significant source of MPs in aquatic environments is the effluent streams from wastewater treatment plants (WWTPs). Although WWTPs are still capable of removing up to 99% of these particles with considerable efficiency, it has been shown that microplastics could bypass the WWTP, entering the aquatic water bodies and finally accumulating in the environment (Carr *et al*., 2016; Murphy *et al*., 2016). A recent study indicated that wastewater treatment plants (WWTPs) potentially played an important role in releasing microplastics to the environment (Browne *et al*., 2011). The synthetic cloths, such as polyester (PES) and nylon, might shed thousands of microplastic fibres into wastewater during the washing process (Napper and Thompson, 2016). Despite their high removal efficiency, wastewater treatment plants (WWTPs) often serve as “hotspots” for microplastic (MPs) pollution, since the concentration of MPs in their discharged effluents is typically much greater by several orders of magnitude than that found in the natural waters they flow into. Abundant MPs are released into the environment, even from the treated effluents and sludge products daily (Ziajahromi *et al*., 2017).

For this research, the study areas selected were: Hariparbat STP (Sewage Treatment Plant), Laam STP and Nishat WTP (Water Treatment Plant). The treated wastewater from the STP is discharged into Dal Lake, which is a habitat for the aquatic life of Srinagar. Additionally, the water from Dachigam is mixed with Dal Lake, and after treatment, is supplied to the households for drinking.

Currently, there are no established regulatory limits for microplastics in drinking water or food products, which makes it challenging to set guidelines or standards for MP contamination levels. While eliminating MPs is currently unfeasible, we can take certain measures to control exposure such as encouraging the use of water filtration systems and providing clean water for animals. Using filtered, microplastic-free water for livestock and poultry can help to reduce its ingestion by these animals. This can lower the amount of Microplastics present in animal products like milk and meat. Hence, this study had two main objectives: (1) to detect microplastics in wastewater treatment plants. (2) to Preparation of a low-cost microplastic filtration model.

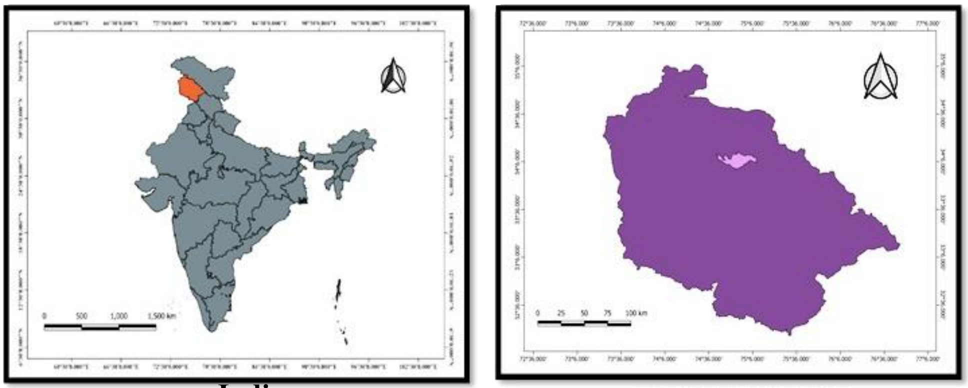
## 2. Materials and methods

### 2.1. Detection of microplastics in wastewater treatment plants

#### 2.1.1 Description of the study site

In this study, we have selected three pivotal treatment plants in Srinagar, namely Hariparbat Sewage Treatment Plant (STP), Laam Sewage Treatment Plant (STP), and Nishat Water Treatment Plant (WTP). These facilities play crucial roles in managing the city's wastewater and water purification needs. The Hariparbat STP, with a capacity of 5.4 MLD and Laam STP, with a capacity of 4.5 million liters per day (MLD), are integral components of the sewage management system around Dal Lake.

The Nishat WTP is one of Srinagar's oldest water treatment facilities. It has a total capacity of 30 MLD. Its long-standing operation underscores its importance in providing potable water to these regions. The study area map of selected treatment plants is shown in Figure 1.



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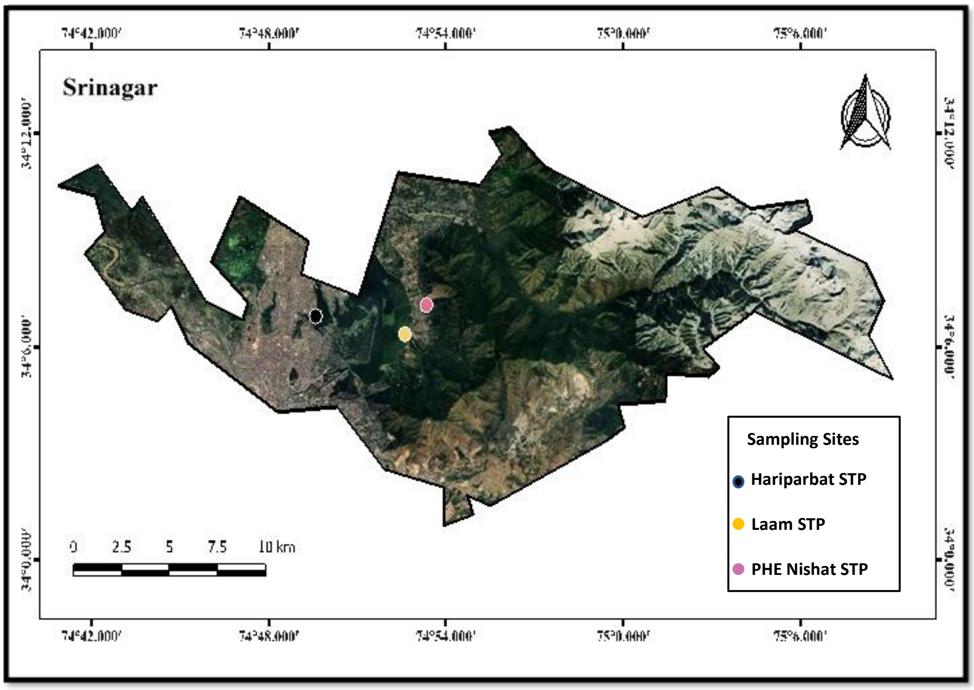


**Figure 1. Study area map of the selected treatment plants (STP/WTP)**

### 2.2.2. Sampling plan

There were three stages in each Sewage Treatment Plant (physical treatment, biological treatment, chemical treatment), whereas the Water Treatment Plant avoids biological treatment. Based on treatment stages, four sample collection points were designated: (1) physical (before physical treatment), (2) biological (before biological treatment), (3) chemical (before chemical treatment) (4) final (effluent). In Nishat WTP, three sample collection points were selected. The aim was to comprehensively assess the treatment process efficacy at each plant. The details of the experimental design are shown in Table 1.

**Table 1:Experimental design for the detection of microplastics in different treatment plants**

| Study site | Srinagar |
|---|---|
| No. of sampling sites | 03 |
| Name of sampling sites | Site I : Laam (4.5 MLD STP)<br>Site II: Nishat (30 MLD PHE WTP)<br>Site III: Hariparbat (5.4 MLD STP) |
| Number of sampling stages | 04 |
| Name of sampling stages | Stage I : before physical treatment (physical)<br>Stage II: before biological treatment (biological)<br>Stage III: before chemical treatment (chemical)<br>Stage IV: Final |
| Number of replications in each stage | 03 |
| Total number of water samples | 33 |
| Statistical technique | Multistage Random Sampling |

### 2.2.3. Sample collection process

Microplastic samples were collected from each sampling stage by gathering 20 litres of water using a bucket. This ensured a sufficient volume for accurate analysis. Following collection, the water was filtered using a 300-micron sieve, allowing for the capture of microplastics while permitting smaller particles and dissolved substances to pass through.

#### 2.2.4. Organic matter digestion and filtration

Organic materials present in the sample were broken down using a chemical solution. 30mL hydrogen peroxide (30% $H_2O_2$) was used overnight for the samples that contained more organic matter. This step was only followed for STPs (Hariparbat and Laam). For the Nishat WTP, this step was not necessary as the water had no organic matter mixed. All the samples were filtered using Whatman filter paper. The supernatant was dried under the sun to remove excess moisture.

#### 2.2.5. Sample identification and characterization

Stereo-microscopy, Fourier Transform Infrared Spectroscopy **(**FTIR) and Scanning Electron Microscopy (SEM) were used to detect, identify, and confirm the presence of various polymers and for the characterization of materials of microplastics.

### 2.3. Preparation of a low-cost microplastic filtration model

#### 2.3.1 Filtration media

The filter media were prepared using three types of materials, which were arranged in different ratios to check the efficiency of the filter (Table 2). Materials utilised in the filter were: activated charcoal, charcoal, and silica sand. Activated charcoal was procured from the registered buyer. Household char was produced by heating organic biomass (apple tree and poplar). This was collected from local sources. Sand was collected from the nearby riverside, and the stones and pebbles were separated using a mesh before arranging them in the filter.

**Table 2: Experimental design of the filtration model**

| S. No | Materials | Treatment | Proportion (cm) | | |
|---|---|---|---|---|---|
| | | | Sand | Activated Charcoal/Charcoal | Sand |
| 1 | Activated Charcoal and sand | $T_1$ | 4 | 2 | 4 |
| | | $T_2$ | 3 | 4 | 3 |
| 2 | Charcoal and sand | $T_3$ | 4 | 2 | 4 |
| | | $T_4$ | 3 | 4 | 3 |
| 3 | Sand | $T_5$ | 10 | 0 | 0 |
| 4 | Number of Replications | | 03 | | |
| 5 | Total number of filtered samples | | 15 | | |
| 6 | Statistical design | | CRD factorial | | |

### 2.3.2. Particle density of silica sand, charcoal and activated charcoal

The particle density of sand, charcoal and activated charcoal was measured using the small pycnometer method (BSI, 1990), and the specific surface area was calculated using the methylene blue absorption technique (Kandhal *et al.*, 1988; Santamarina *et al.*, 2002). Table 3 shows the particle density and the specific surface area of all the materials used in the filter.

**Table 3: Particle density and Specific surface area of sand, charcoal and activated charcoal**

| Materials | Particle density ($g/cm^3$) | Specific Surface Area (SSA) ($m^2/g$) |
|---|---|---|
| Activated Charcoal | 0.72 | 360 |
| Charcoal | 1.25 | 88.15 |
| Sand | 2.73 | 3.67 |

### 2.4. Statistical analysis

All data were recorded by repeating each measurement three times, and the results are presented as mean ± standard error (Se). To determine significant differences between treatment stages and sites, analysis of variance (ANOVA) was performed at a 95% confidence level ($p \leq 0.05$). Critical Difference (CD) values were calculated to compare mean values across different stages. Statistical analysis ensured that the observed differences in microplastic abundance and size were reliable and not due to random variation.

## 3. Results and discussion

### 3.1. Detection of microplastics in wastewater treatment plants

### 3.1.1. Shape of microplastics

The shapes of the microplastics were studied at different stages of treatment plants using stereo-microscope and Scanning Electron Microscope (SEM). On set of the shapes of fibres, fragments, films, foams, and cross-network fibres were observed in Hariparbat and Laam STPs. Microplastics of the same shapes were also found before the biological stage.

The plastic particles present in maximum amount were found as cross-network fibres and microfibres, followed by micro-fragments, microfilm, and microfoam. Microfibres were found in the maximum amount at the physical stage of each treatment plant; however, there was a significant reduction of microfibres noticed after the biological stage. Iyare *et al.* (2020) also reported that biological treatment removed microplastics approximately 80–90% as the microplastics (mostly microfibres) get trapped by microbial biomass and form biofilms.

After biological treatment, the number of microplastics was reduced. At Hari Parbat STP, only fragments and fibres were left, while in Laam STP, the remains were fragments, fibres, foams, and films. This could only mean that Hari Parbat STP was more effective in removing microplastics compared to Laam STP. Cross-network fibres were fully removed at both plants by the biological stage. After the chemical treatment (final stage), only a few films and fibres were seen in Hari Parbat. In Laam, fibre, fragment, and film were still present, but foam was completely gone.

In Nishat WTP, cross-network fibres and foam were not found. Due to the absence of biological stage in WTP, the microplastic removal efficiency was observed to be low compared to STPs. Before the physical stage, the shapes of fibre, fragment, and film types were found. After the physical stage, the same types remained. A very few number of fibres were detected in Nishat WTP. After chemical treatment (final stage), only film and fragment shapes of microplastics were found. At Nishat WTP, there were very few microplastics detected in the initial stage, as the source of water is Dachigam side, mixed with Dal Lake water, was relatively clean during the sample collection time. Additionally, the larger volume of water in WTP (30MLD) might have reduced the density of microplastics. Microfilm were the most common shape found in the sample, followed by microfragment and microfibres. In the final stage, film and fragment were still present, indicating their resistance to treatment and difficulty in being filtered out. The fact that fibres and films were still found in the final water shows that these types of plastics are hard to remove with normal treatment methods. This means better filters or advanced technologies are needed to stop microplastic pollution. Table 4 provides a list of different microplastic shapes found in each stage of the treatment plants, and Figure 2 includes the photographs of identified microplastic shapes.

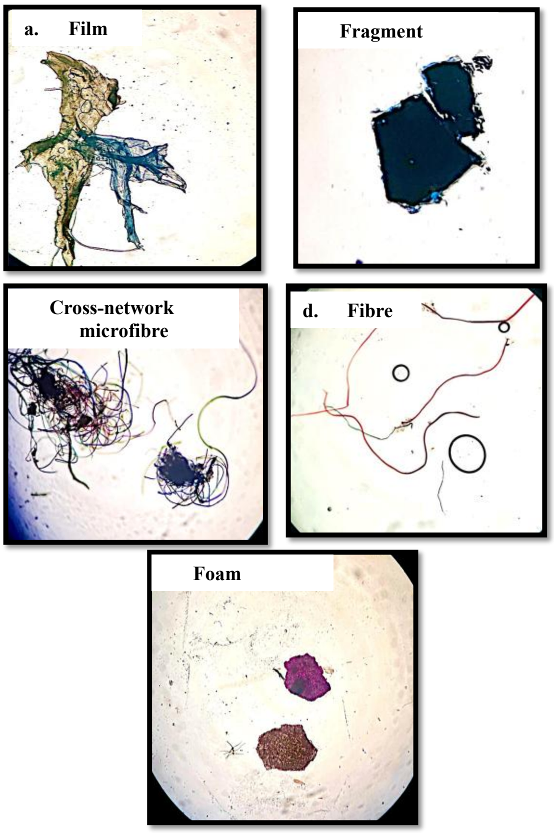


**Figure 2. Different forms of microplastics identified under a stereomicroscope from treatment plant samples showing (a) film, (b) fragment, (c) cross-network microfibre, (d) fibre and (e) foa**

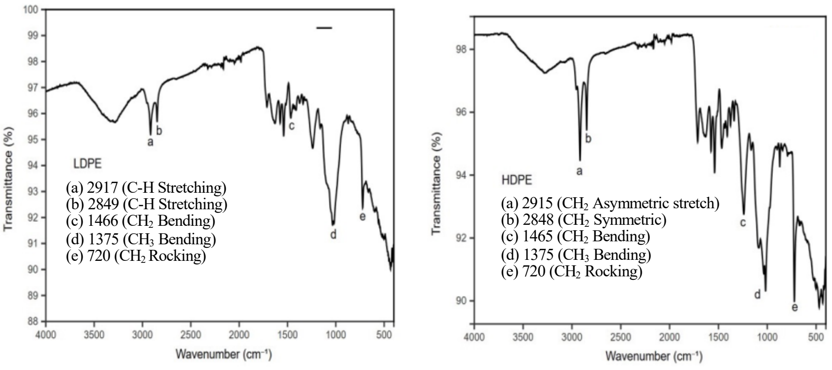
**Table 4: Types of microplastics on the basis of shapes in each stage of STP/WTP**

| S.No. | Treatment plants | Stages | | | |
|---|---|---|---|---|---|
| | | **Physical** | **Biological** | **Chemical** | **Final** |
| **1.** | **Hari Parbat STP** | Fibre, Fragment, Film, Foam, Cross-networks | Cross-networks, Fibre, Foam, Film, Fragment | Fragment, Fibre | Film, Fibre |
| **2.** | **Laam STP** | Fibre, Cross-network fibres, Fragment, Film, Foam | Fragment, cross-networks, Fibre, Foam, Film | Fragment, Fibre, Foam, Film | Fibre, Fragment, Film |
| **3.** | **Nishat WTP** | Fibre, Fragment, Film | __* | Film, Fibre, Fragment | Film, Fragment |

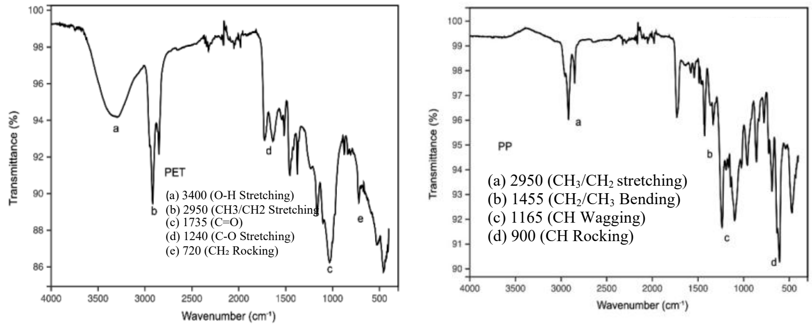
### 3.1.2. Polymer types

Analysis of microplastic composition was carried out in the three different water treatment plants: Hari Parbat STP, Laam STP and Nishat WTP using FTIR to identify the polymer type. The polymeric profile across these sites demonstrated the widespread presence of five major plastic polymers: Polyethylene (HDPE/LDPE), Polypropylene (PP), Polyethylene Terephthalate (PET), Polyacrylonitrile (PAN), and Polyvinyl Chloride (PVC). At Hari Parbat, all five polymers were identified. This indicated a strong presence of packaging, textile, and domestic waste-related sources. Similarly, the Laam STP exhibited the same variety of polymers, reflecting similar waste inputs. In contrast, the Nishat plant exhibited a slightly narrower range, containing PAN, HDPE/LDPE, and PP. This might suggest a dominant presence of textiles and consumer plastics, but relatively fewer packaging-related PET and PVC items.

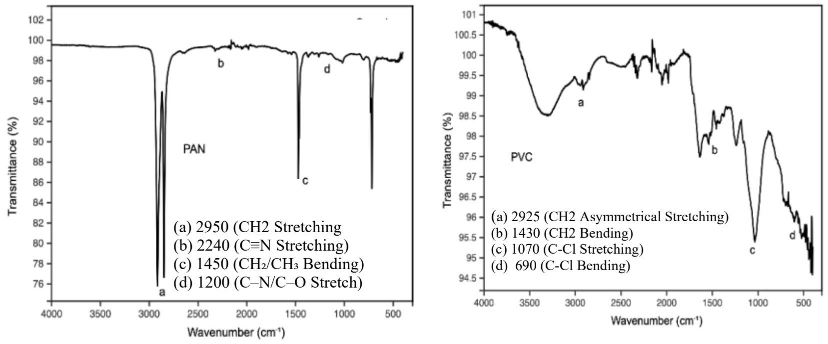
The type of polymer found in the highest concentration in STPs (Hariparbat and Laam STP) was PET (polyester), followed by PP (Polypropylene) and PE (Polyethylene). PET (Polyester) and PP (Polypropylene) were the most abundant polymers found in water treatment plants, which are commonly found in microfibres (Carr *et al.*, 2016). The microfibres are a type of microplastic released from the washing of clothes and textiles, with polyester (PET) being the most common type of polymer (Murphy *et al.*, 2016). Another microplastic polymer detected in STP was PAN (Polyacrylonitrile); this polymer is commonly used in synthetic textiles and is very persistent in the environment. Ziajahromi *et al.* (2017) also reported that the presence of acrylic fibres was detectable in both influent and effluent of WWTPs. Figure 3 presents the FTIR spectra showing strong resemblance with all the identified polymers.



**LDPE polymer** **b. HDPE polymer**



**PET polymer** **PP polymer**



**PAN polymer** **PVC polymer**

**Figure 3. FTIR spectra representing the characteristic functional groups of various polymer types: polyethylene terephthalate (PET), polypropylene (PP), polyacrylonitrile (PAN) and polyvinyl chloride (PVC) identified from microplastic samples obtained from sewage treatment plants (STPs) and water treatment plants (WTPs)**

### 3.1.3. Abundance of microplastics

The abundance of microplastics (MPs) was assessed using a stereo-microscope across three sewage treatment plants: Hariparbat STP, Laam STP, and Nishat WTP. The results are shown in Table 5 for both the particle count and abundance (%) at each treatment stage.

In Hariparbat STP, the physical stage had the highest concentration of MPs, with 329.7 ± 8.87 particles/20L (62.24 % abundance). After the physical treatment, microplastics are reduced to 196.7 ± 3.48 particles/20L (37.13 % abundance). After the biological stage, the microplastics count dropped to 2.33 particles/20L (0.44 % abundance). The final water contained just 1 particle/20L (0.19 % abundance) after chemical treatment.

In Laam STP, microplastics of 99.67 ± 4.05 particles/20L were recorded in the physical stage (59.09 % abundance). This was reduced to 58 ± 1.53 particles/20L for the biological stage (34.39 % abundance) and then to 8.67 ± 0.88 particles/20L (5.14 % abundance) before the chemical stage. In the final stage, 2.33 ± 0.33 particles/20L were found (1.38 % abundance).

In Nishat WTP, the initial microplastics count was 4.33 ± 0.33 particles/20L (68.41% abundance). The microplastic count decreased to 1.33 ± 0.33 particles/20L (21% abundance) after the physical treatment. The final treated water still contained 1 particle/20L (10.58 % abundance).

Overall, Hariparbat STP had a very high number of microplastics (329.7 ± 8.87 particles/20L) in the initial stage, followed by Laam STP (99.67 ± 4.05 particles/20L) and Nishat WTP (4.33 ± 0.33 particles/20L). The highest concentrations were consistently recorded before the physical treatment stage, indicating a substantial microplastic load in the raw influent. This continued presence of microplastics in treated water underscores the limitations of conventional wastewater treatment systems in capturing microplastics, particularly those with a smaller size or lighter density, such as fibres and films (Carr *et al.*, 2016; Talvitie *et al.*, 2017).

**Table 5: Abundance of microplastics in Hariparbat STP (5.4 MLD STP)**

| Treatment plants | Abundance (particles/20L) | | | | Avg MPs (particles/20L) | CD | Per-day release (Particles/day) |
|---|---|---|---|---|---|---|---|
| | Physical stage | Biological stage | Chemical stage | Final stage | | | |
| Hariparbat STP | 329.7± 8.87 (62.24%) | 196.7± 3.48 (37.13%) | 2.33± 0.33 (0.44%) | 1.00 (0.19%) | 132.43± 3.17 | 7.96 | $2.7 \times 10^5$ |
| Laam STP | 99.67±4.05 (59.09%) | 58±1.53 (34.39%) | 8.67±0.88 (5.14%) | 2.33±0.33 (1.38%) | 42.17±1.70 | 9.89 | $5.24 \times 10^5$ |
| Nishat WTP | 4.33±0.20 (68.41%) | 1.33±0.33 (21.01%) | 0.67±0.33 (10.58%) | - | 2.22±0.62 | 2.58 | $1.00 \times 10^6$ |

### 3.1.4. Microplastic removal efficiency of treatment plants

In Hariparbat STP, the physical stage removal efficiency was 40.34%. Studies have shown that the physical stage in treatment plants usually removes 30-60% of MPs (Carr *et al.*, 2016). The biological stage was highly effective at removing microplastics (98.82%). Studies found that biological treatments can remove over 90% of microplastics by helping them stick to sludge particles (Lares *et al.*, 2018). The chemical treatment reflected an additional 57.08% removal of microplastics from the biological treatment, which is moderate and depends on the chemicals used (Sun *et al.*, 2019). The overall MP removal efficiency from the physical to the final stage was 99.70%.

In Laam STP, the physical removal of microplastics was 41.77%. After the biological stage, microplastic removal was up to 85.05%. The biological stage removal was slightly lower due to factors like retention time and operational conditions. Talvitie *et al.* (2017)

reported that biological treatment helps to remove microplastics mainly through sludge formation and settling. The chemical stage showed a 73.12% removal from the previous stage. The overall removal efficiency from the physical to the final treated water was 97.66%.

In Nishat WTP, the physical treatment achieved 69.28% removal efficiency. The chemical stage showed 49.62% removal in the final stage. As WTPs do not use any biological stage, the overall removal dropped to 84.52%. The combination of all the three stages gives the best MP removal, and the biological stage is the most important for removing microplastics (Lares *et al.*, 2018). Although the initial concentration of microplastics was low in Nishat, there was a high proportion of microplastics remaining in the final effluent, which suggests a need to improve the final treatment process.

Table 6 presents the removal efficiency for each treatment stage as well as the overall efficiency across all three treatment plants. Figure 4 presents a bar chart of removal efficiency at each treatment stage.

**Table 6: Microplastic removal efficiency at each stage in different treatment plants**

| STP/WTP | Removal Efficiency (%) | | | Overall Removal Efficiency (%) |
|---|---|---|---|---|
| | Physical Stage | Biological Stage | Chemical Stage | |
| **Hariparbat** | 40.34 | 98.82 | 57.08 | 99.70 |
| **Laam** | 41.77 | 85.05 | 73.12 | 97.66 |
| **PHE Nishat** | 69.28 | — | 49.62 | 84.52 |

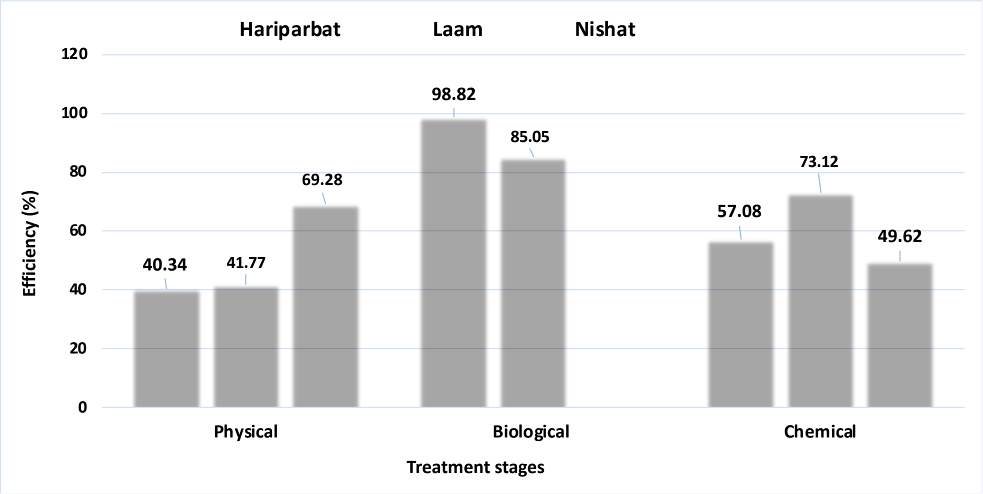


**Figure 4. Stage-wise comparison of microplastic removal efficiency (%) in different types of treatment facilities (wtps and stps), highlighting variations in removal performance across treatment Processes**

### 3.1.5. Size of microplastics

SEM revealed considerable variation in both the shape and size of the microplastics. The size of each shape was measured and expressed as a range from maximum to minimum, and the average size was expressed with standard error (Mean ± SE), as shown in Table 7. At the Hari Parbat STP, the largest microplastic shape observed was the cross-network fibres, with sizes ranging from 4318.28 µm to 2555.22 µm. These fibres had an average size of 3714.56 ± 881.53 µm. Films were the second largest, showing a wide variation in size from 5069.24 µm to 399.17 µm, with the average size of 1744.95 ± 861.06 µm. Followed by film, the fibres were found to have a range between 4300.03 µm to 127.36 µm, with an average size of 1588.39 ± 306.04 µm. Next to fibres, foams were found with a size range between 2506.85–751.38 µm, with an average size of 1455.78 ± 178.87 µm. Fragments were the smallest of all observed shapes, with a size range from 1308.32 µm to 80.12 µm and an average size of 524.09 ± 99.35 µm.

At Laam STP**,** cross-network fibres were once again found to be the largest shape of microplastics, ranging from 4066.67 µm to 313.73 µm**,** with an average of 1511.02 ± 520.57 µm. The fibres were the second largest shape of microplastics found in Laam STP. This showed a wide size distribution, from 3792.53 µm to 12.46 µm, with an average size of 1278.4 ± 303.49 µm. Followed by fibres, films were found with a size distribution between 1977.87 µm and 482.04 µm, with a mean size of 960.14 ± 220.24 µm. Next to fibres, the foam-shaped microplastics were found to have a size range between 1145.65 µm to 420.30 µm, with an average of 581.38 ± 84.52 µm. Lastly, fragments were again the smallest shape found among all shapes of microplastics, ranging between 1343.41 µm and 119.04 µm, with an average size of 569.07 ± 205.16 µm.

At the PHE Nishat STP, only films, fibres, and fragments were detected. Films were the largest among them, with an average size of 1475.39 ± 348.49 µm, and sizes ranging from 2132.85 µm to 946.27 µm. Next to films, fibres were found varying between 3476.21 µm and 295.29 µm, with a mean of 1261.73 ± 595.06 µm. Fragments were the smallest shape recorded, ranging from 492.37 µm to 20.19 µm, and had an average size of 148.66 ± 114.83 µm. The foam and cross-network fibre types were not present at this site.

Out of all types of microplastics, the largest size was found to be cross-network fibres (3714.56 ± 881.53 µm) from Hariparbat STP, and the smallest was fragments (148.66 ± 114.83 µm) from Nishat WTP.

**Table 7: Distribution of microplastics on the basis of size (µm)**

| STP/WTP | FIBRE | | FRAGMENT | | FILM | | FOAM | | CROSS-NETWORK | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Range | Mean ± Se | Range | Mean ± Se | Range | Mean ± Se | Range | Mean ± Se | Range | Mean ± Se |
| Hariparbat | 4300.03-127.36 | 1588.39±306.04 | 1308.32-80.12 | 524.09±99.35 | 5069.24-399.17 | 1744.95±861.06 | 2506.85-751.38 | 1455.78±178.87 | 4318.28-2555.22 | 3714.56±881.53 |
| Laam | 3792.53-12.46 | 1278.4±303.49 | 1343.41-119.04 | 569.07±205.16 | 1977.87-482.04 | 960.14±220.24 | 1145.65-420.30 | 581.38±84.52 | 4066.67-313.73 | 1511.02±520.57 |
| PHE Nishat | 3476.21-295.29 | 1261.73±595.06 | 492.37-20.19 | 148.66±114.83 | 946.27-2132.85 | 1475.39±348.49 | - | - | - | - |

Overall, cross-network microfibres, fibres and films were the largest microplastics found in Hariparbat STP. On the other hand, fragments were the smallest shape found in PHE Nishat WTP. This size variation can be due to the origin and degradation process of plastics. The cross-network microfibres or the large fibres are likely released from synthetic textiles or fishing gear, whereas smaller fragments are usually created when bigger plastic items break down over time (Auta *et al*., 2017). The fact that some shapes were missing at certain sites may be due to the variations in local pollution sources or environmental conditions, such as water flow or treatment methods. Figure 5 illustrates the average sizes of different microplastic shapes using a bar chart, whereas Figure 6 shows clear SEM images used to measure sizes.

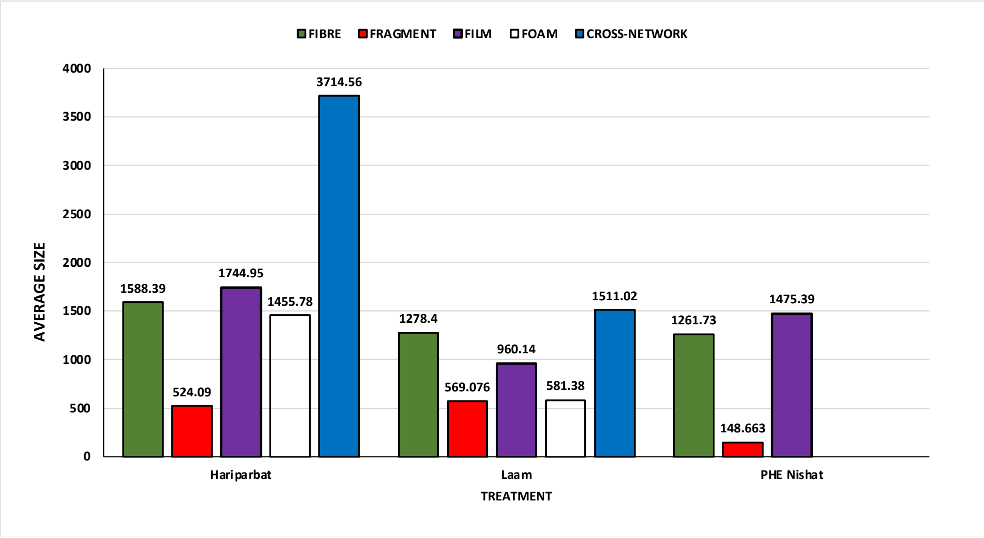
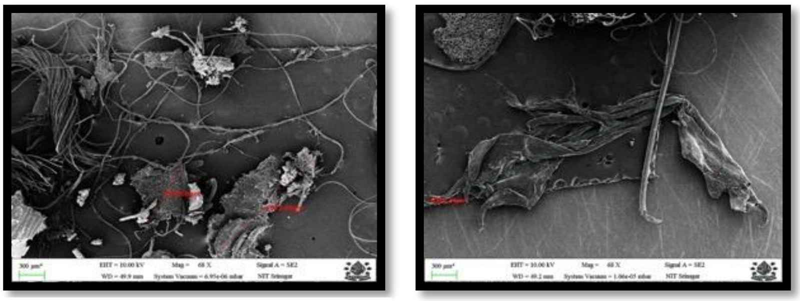


**Figure 5. Comparison of average sizes of different types of degraded microplastics (fibre, fragment, film, foam and cross-network) across various water treatment plants (Hariparbat, Laam, and PHE nishat)**

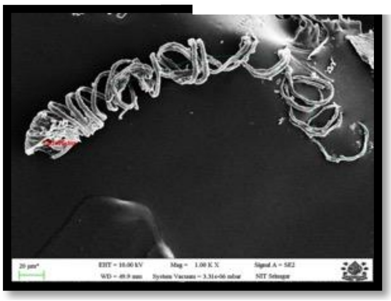
**a. Foam (Mag: 200KX)**

**b. Cross-network microfibre (Mag: 68X)**



**c. Fibres and Fragments (Mag: 68X)**

**d. Film (Mag: 68X)**



**e. Fibre (Mag: 1.00KX)**

**Figure 6. Scanning Electron Micrographs (SEM) showing morphological diversity of microplastic particles isolated from wastewater: (a) foam, (b) cross-network microfibres, (c) fragment, (d) fibre and (e) film observed at magnifications of 200X–1.00KX**

## 3.2. Preparation of a low-cost microplastic filtration model

### 3.2.1 Model efficiency (%)

A total of five different filter combinations were used to find the efficiency of the sand-char filter to trap microplastics (Table 8). Among all filters (Figure 7), the sand-activated char type-1 filter demonstrated the highest removal efficiency of 99.50 %, reducing MPs from 100 particles/L to 0.5 particles/L. The results were significant with sand-activated charcoal type-2, which achieved 99.17 % efficiency (0.835 particles/L in the effluent). The sand-char type-1 filter also showed a very high efficiency of 99.00 % (1 particle/L in effluent), while the sand-char type-2 filter showed 98.84 % efficiency (1.16 particles/L in effluent). In contrast, the plain sand filter (10 cm) showed the lowest performance, with an efficiency of 97.16 %, reducing MPs up to 2.84 mp/L.

These results showed that including activated charcoal or charcoal with sand significantly enhances microplastic removal efficiency compared to sand alone. Similar patterns were reported by Bhatnagar & Sillanpaa (2010), and showed that one of the main reasons was the specific surface area (SSA). Activated charcoal has a very large surface area (360 $m^2/g$), compared to charcoal (88.15 $m^2/g$) and sand (3.67 $m^2/g$) (Table 3). A larger surface area provides more pores and spaces to trap microplastics, increasing adsorption efficiency (Xu *et al.*, 2018). Although charcoal had a lower SSA compared to activated charcoal, it performed well along with sand, especially when used with sand, due to its moderate surface area and porous structure. It is also known to support the adsorption of various pollutants in water treatment (Bhatnagar & Sillanpaa, 2010).

The particle density of the filter materials also plays an important role. Activated charcoal is the lightest (0.72 $g/cm^3$), followed by charcoal (1.25 $g/cm^3$) and then sand (2.73 $g/cm^3$) (Table 3). Lighter materials are usually more porous and can hold water for a longer time, which increases the contact between microplastics and the filter surface. This enhances the chance of microplastics getting trapped through adsorption (Mohan & Pittman, 2006). Although charcoal is heavier than activated charcoal, it is still much lighter and more porous than sand. These properties improve its ability to retain particles during filtration. This explains why sand-char filters performed almost as well as activated charcoal filters.

The design of the filter layers plays a significant role in their filtration efficiency. The 4:2:4 (cm) design (sand-charcoal-sand/sand-activated charcoal-sand) showed slightly better results than the 3:4:3 (cm) design, even though the same material was used. This may be because the thicker sand layers on top and bottom help to catch larger particles first, and the middle layer (charcoal or activated charcoal) removes smaller ones. This type of layered structure improves filter compaction, water flow control, and contact time, which together enhance the overall filtration performance (Talvitie *et al*., 2017). Additionally, in the 4:2:4 (cm) filter design, the thicker sand layers put greater downward pressure on the central charcoal layer. This leads to tighter packing and may slow the flow of water, thereby increasing retention time and improving microplastic removal compared with the 3:4:3 (cm) filter design (Worch, 2012).

Overall, the choice of filter material and design affects microplastic removal efficiency. It is preferred to use layered sand-charcoal filters to make the treatment more effective.

**Table 8: Filtration efficiency of different models for microplastic removal (%)**

| S. No. | Filter types | Ratio (cm) | MPs in Influent (Particles/L) | MPs in effluent (particles/L) | Efficiency (%) |
|---|---|---|---|---|---|
| 1. | Sand:activated charcoal:sand (type-1) | 4:2:4 | 100 | 0.50 | 99.50 |
| 2. | Sand:activated charcoal:sand (type-2) | 3:4:3 | 100 | 0.84 | 99.17 |
| 3. | Sand:char:sand (type-1) | 4:2:4 | 100 | 1.00 | 99.00 |
| 4. | Sand:char:sand (type-2) | 3:4:3 | 100 | 1.17 | 98.84 |
| 5. | Plain sand | 10 | 100 | 2.84 | 97.16 |
| | **CD (≤0.05)** | | | **0.996** | |

a. Sand-activated char filter b. Sand-char filter c. Sand filter

**Figure 7. Low-cost filter models for microplastics filtration: a. sand-activated char filter, b. sand-char filter, and c. sand filter.**

### 3.2.2 Cost analysis

A comparative cost analysis was carried out for three different types of filters having a 5-litre capacity as mentioned in Table 9. For this analysis, the filter with better efficiency from the sand-activated char and sand-char filters was considered.

The sand-activated charcoal filter emerged as the most expensive option, with a cost range of ₹125 to ₹215, having the highest efficiency of 99.5 %. This filter can be considered if higher removal performance and durability are prioritised. The Sand-char type filter was moderately priced, ranging from ₹50 to ₹70, with 99 % efficiency. This filter offered a balance between affordability and filtration efficiency, making it a practical option for routine use with satisfactory results, as charcoal-based filters are widely recognised for being low-cost yet effective adsorbents (Mohan & Pittman, 2006). On the other hand, the plain sand filter had a price range of ₹40 to ₹60. It had the lowest cost as well as the lowest efficiency among all the filters, since it relies solely on physical straining and lacks the adsorption capabilities provided by charcoal or activated carbon.

Although cost plays a crucial role in filter selection, efficiency should be equally considered to ensure optimal microplastic removal based on the treatment needs.

**Table 9: Cost analysis for preparation of a 5-Litre capacity filter (₹)**

| S No | Filter types (5L capacity) | Cost (₹) |
|---|---|---|
| 1 | Sand-activated charcoal | 125 - 215 |
| 2 | Sand-char type | 50 - 70 |
| 3 | Plain sand | 40 - 60 |

### 3.2.3 Filter preference

The sand-char filter was ranked as the most preferred option, demonstrating a high removal efficiency of 99.00 % at a cost range of ₹50–70 for a 5-litre capacity. Although performance was marginally lower than that of the sand-activated charcoal filter (99.50 %), the cost was significantly more affordable. This makes sand-char an economical and practical alternative, particularly in such places where people cannot afford more expensive filtration systems. It is a sustainable solution to combine the sand for mechanical filtration and regular charcoal for the adsorption of contaminants, as these materials are locally available. Similar findings were reported by Loo *et al*. (2012) and Mwabi *et al*. (2012).

## 4. Conclusion

In the first objective of this study, common polymers identified from the treatment plants using FTIR spectroscopy were LDPE, HDPE, PET, PP, PAN, and PVC. The maximum number of microplastics was detected in Hariparbat STP, followed by Laam STP, and the least in Nishat WTP, due to the relatively cleaner influent from the Dachigam source and high capacity (30 MLD) of the treatment plant. The smallest MPs detected were fibres at 12.46 μm (Laam STP) and fragments at 20.19 μm (Nishat WTP). The largest MPs were films up to 5069.24 μm (Hariparbat STP) and cross-network fibres up to 4318.28 μm (Hariparbat

STP). Hariparbat STP (99.70%) had the highest removal efficiency, followed by Laam STP (97.66%) and Nishat WTP (84.52%). As Nishat WTP does not use biological treatment, improving its physical filtration process could significantly enhance microplastic removal.

For the second objective, among the five low-cost filter models sand-activated charcoal (4:2:4 cm) filter had the highest removal efficiency (99.50%), followed closely by the sand-char filter (99%) and the plain sand filter (97.16%). Filter containing activated charcoal performed better than other media due to its high surface area (360 $m^2/g$), while charcoal (88.15 $m^2/g$) also performed well due to its porosity, moderate surface area. The performance of charcoal was enhanced due to the combination of sand. Filter performance was influenced by layer design, material properties, with 4:2:4 cm layers outperforming 3:4:3 cm designs. Activated charcoal and charcoal were more effective than sand alone. The sand-char filters (₹50–70) proved to be the most cost-effective for widespread decentralised usage.

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