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Microplastic Pollution in Shoreline Sediments of Selected Rivers of Mizoram, North-East India: A Baseline Assessment and Preliminary Report

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ABSTRACT

Microplastics have emerged as another dimension of hazardous and persistent pollutants afflicting every corner of the globe, even permeating critical biodiversity hotspots. This study aims to serve as a preliminary report on the occurrence and assessment of MP pollution in shore sediments of four selected rivers in the state of Mizoram, which lies in one of the sensitive biodiversity hotspots in India, and is also a part of the eastern Himalayan range. There have been minimal studies on microplastic pollution in this region despite its critical ecological location. Four freshwater rivers, namely Chite, Tlawng, Serlui-A, and Tuirial, were selected for the study due to their proximity to urban settlements and have been subjected to rampant plastic pollution. The study revealed that MPs were detected from all sampling sites, and abundance was highest in Chite, which runs through parts of Aizawl city. Particles within the size range of 0.15-0.25 mm were found to be the highest in numbers in all sampling locations, while MPs between 3-5 mm were the least in number. The shapes of MPs were varied, constituting fragments, fibers, pellets, and spheres, with fibers (40%) being the dominant shape overall. Polyethylene was found to be the dominant polymer type among particles analyzed using FTIR spectroscopy. This study contributes to the imperative assessment of MP pollution in river sediments of the eastern Himalayan region of India, as comprehensive research in this regard is still lacking.

1. INTRODUCTION

Plastics are an indispensable part of modern life, and they are used extensively in all parts of the globe. However, their indiscriminate use and improper disposal, along with inadequate and futile recycling efforts, have contributed to the massive scale of plastic pollution in all types of environments, both terrestrial and aquatic (Rhodes 2018, Bajt 2021). Consequently, plastic pollution has yielded another dimension of hazardous pollutants in the form of microplastics (MPs), which are classified as minuscule plastic objects that range in size between 0.1 and 5mm (Desforges et al. 2014). These particles have been categorized as pollutants of emerging concern, and their detection has been reported in terrestrial and aquatic ecosystems, in the air, and even inside the tissues of living organisms, including humans (Smith et al. 2018, Goyal et al. 2023, Zhao et al. 2023). Aquatic environments, in particular, are highly susceptible to MP pollution, due to surface water run-offs that carry MP particles from anthropogenic sources such as industries, agricultural fields, waste dumping grounds, and even personal care products (Rhodes 2018, Koelmans et al. 2019). Plastics are manufactured with the addition of various chemicals additives to enhance the quality and performance of the products such as dyes, lubricants, plasticizers, flame retardants, heat stabilizers and anti-microbials (Smith et al. 2018, Sendra et al. 2021) and several studies have suggested that there is a high possibility of these substances leaching into their immediate environment via ingested MPs, leading to deleterious effects in living systems that ingest them directly or indirectly (Bridson et al. 2023, Gulizia et al. 2023). MP pollution in aquatic environments, both freshwater and marine, is particularly concerning due to their positions as critical entry points into the food chain, which may lead to bioaccumulation and subsequently affect a wide range of organisms, including humans. Numerous studies have reported such findings (Cole et al. 2014; Van Cauwenberghe & Janssen 2014, Krause et al. 2021, Patil et al. 2022, Gunaalan et al. 2023). MPs of different size ranges have been detected in both freshwater and marine environments all across the globe, in different continents, and such identifications have been reviewed extensively (Xu et al. 2021, Vivekanand et al. 2021; Wang et al. 2022). MPs have been classified into various categories depending on their physical characteristics, such as fragments, pellets, filaments, and granules. Chemically, MPs generally constitute monomers of polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC), high-and low-density polyethylene (HD/LD-PE), etc. (Anbumani & Kakkar 2018).

MPs in rivers accumulate through numerous sources, including household hygiene items that are used for bathing and cleansing clothes, plastic waste, and fabric waste (Ghosh et al. 2023). Washing synthetic fabrics can result in the generation of significant amounts of microplastic fibers (MFs) in wastewater, which can then enter river systems (McCormick et al. 2016). Additionally, extensive use of fishing nets and lines that are left in the water, angling, and other techniques used to catch fish (Ghanbari et al. 2022, Karthikeyan et al. 2023) also contribute to MP contamination. Other prominent sources include vehicle tires, city dust, and road markings (Ramaremisa et al. 2022). Several freshwater systems serve as major routes for improperly managed plastic debris to enter the oceans. It has been reported that roughly 80% of plastic debris enters the oceans from land-based waste via streams and rivers and is further weathered by the natural elements into smaller particles such as MPs (Wang et al. 2024).

This issue of MP pollution has gained considerable concern and traction, especially within the last decade, due to its persistence and ubiquity in all corners of the globe. Considering the possible havoc they reportedly wreak on living organisms that are exposed to these particles, detection and analysis of the extent of pollution in different ecosystems are urgently warranted, especially in areas such as biodiversity hotspots, where their effects could be disastrous. One such example is the state of Mizoram in the eastern Himalayan region of India. The state is a small landlocked region in the north-east corner of the country that lies within one of the recognized biodiversity hotspots in the world (Pautu et al. 2023) and boasts endemic and new species of plants and animals being discovered constantly. Although plastic pollution is a persistent problem that has devastated several river systems within the state as well as other rivers in the Himalayan region, there is still an acute lack of studies pertaining to the extent and impacts of MP presence and pollution in the rivers of Mizoram. Most studies focusing on MP pollution in India have been limited to the sediments and waters of the eastern and western coastal regions, with minimal reports from inland water bodies in the Himalayan regions (Tsering et al. 2021).

Aizawl, the capital of Mizoram, is a densely populated city situated in the northeast corner of India. Being the largest and most heavily populated city in the state, it has also seen a rapid increase in plastic pollution, especially within the last two decades, and improper disposal of garbage has considerably polluted several rivers and streams that are close to the urban settlements. One study by Singh et al. (2023) quantifying plastic waste generation in Aizawl city reported plastic consumption of 13.06 g/capita/day, with plastic packaging contributing the most, followed by carry bags in residential, commercial, and dumping areas. This study also highlights the frequent improper disposal of these plastic wastes that choke drains and eventually make their way into streams and rivers. An unfortunate example is the Chite river, which runs through certain areas of Aizawl city, and indiscriminate dumping of plastic garbage has severely decimated this river. Although there is evident plastic pollution in the rivers that are in proximity to Aizawl, there has been no comprehensive study on the detection and extent of MP pollution. Determining the degree of pollution in these freshwater rivers is crucial, since they are critical lifelines for the people. One of these rivers selected for the assessment, Serlui-A, is the source of drinking water for the municipality of Aizawl. Another river selected for the study, Tuirial, also lies close to the Aizawl municipal garbage dumping ground, rendering it extremely vulnerable to MP runoff. Since there have been minimal investigations to evaluate plastic and MP occurrence in the state, this study, therefore, aims to address this existing data gap for the first time in this region. The investigation serves to provide a baseline assessment of MP pollution in riverbank sediments of selected rivers that are close to residential and commercial settlements, namely Chite, Tuirial, Tlawng, and Serlui-A, during the late monsoon (September, 2023). However, since this study was conducted as a preliminary baseline assessment (as no prior studies have been done in this regard) and no funding was received for the work, only one time point (i.e., late monsoon) has been selected to gauge the extent of MP pollution in riverbank sediments.

2. MATERIALS AND METHODS

2.1. Site of Study

This study was conducted in four selected rivers of Mizoram, north-east India, which lies in the Eastern Himalayan region (Fig. 1). The four rivers, namely, Chite, Tlawng, Tuirial, and Serlui-A, were selected based on their proximity to residential and commercial areas as well as their susceptibility to waste runoff from urban areas. Detailed information regarding the sampling sites is given in Table 1. Their location is a cause for higher susceptibility to plastic pollution as a result of high population density, as well as prevalent cases of improper garbage disposal in and around the municipal areas. Chite flows into Tuirial River, and Serlui-A is also a tributary of Tlawng. Sample collection sites are shown in Fig. 2.

Fig. 1: Google Map showing the geographical location of the study site, i.e., Mizoram, north-east India.

Table 1: Location details of the sampling sites.

Sl.No	River	Latitude and Longitude	Population Degree	River Section
1.	Chite	23°43′59.2″ N, 92°44′17.5″ E	Urban	Upstream
2.	Tlawng	23°42′43.46″ N, 92°39′51.17″ E	Rural	Upstream
3.	Serlui A	23°54′00″ N, 92°36′36″ E	Rural	Downstream
4.	Tuirial	23°43′07″ N, 92°47′58″ E	Semi-urban	Downstream

Fig. 2: Collection sites of shore sediment samples. (A) Google Maps showing locations of study sites in Tlawng and Serlui-A. (B, C) Sample collection sites in Tlawng and Serlui-A, respectively (D, E). Google Maps of Chite and Tuirial, respectively. (F, G) Sample collection locations in Tuirial and Chite, respectively.

2.2. Collection of Samples

Sample collection was performed as per the method stated by Tibbetts et al. (2018). In brief, sediment samples were collected from a selected site on the banks of the four selected rivers, and all samples were collected in September 2023, i.e., the monsoon season, when there is an increased rate of rainfall and water flow in rivers.

At all collection sites from each riverbank, samples from four different spots at depths of 10 cm were collected with a small steel shovel into 250 ml glass beakers, which resulted in a 1 kg bulk sample of sediment (n=3). Two samples were collected with a distance of approximately 3 feet between collection sites, and the other two were collected 10 feet from the previous two and again spaced approximately 3 feet from each other (Tibbetts et al. 2018). The sediment samples from each river were stored in steel containers prewashed with distilled water and then brought into the laboratory for further treatment. The 1 kg mass of sediments from each river was covered using aluminum foil right after collection to prevent plastic contamination. The materials that were used for collecting sediments were cleaned with filtered or distilled water to wash off other contaminants and plastics (Sarijan et al. 2018).

2.3. Sample Processing

The sediments were sieved into five different fractions using brass test sieves having mesh sizes of 5 mm, 3 mm, 1 mm, 0.5 mm, 0.25 mm, and 0.15 mm (Manikarn test sieve, MSWLABS, India). Hence, the size range for each fraction is 0.15-0.25 mm, 0.25-0.5 mm, 0.5-1 mm, 1-3 mm, and 3-5 mm. Larger stone particles and other kinds of identifiable organic debris visibly larger than 5 mm were identified and manually removed. The sediments were wet-sieved with filtered water to speed up the process and to separate the sediments and MPs into their respective fraction sizes. The sieved sediments with 5 different size fractions were then transferred to separate 250 ml beakers, and all beakers were marked with their river source. All beakers were covered with aluminum foil to prevent contamination by plastics from the surroundings. Excess water contained in the sediments was carefully removed with filter paper. Alkali digestion using 10% KOH was done to remove any remaining organic matter, at a volume ratio of 1:3 (Saad et al. 2022). Sediment samples were dried in a hot air oven for 45 hours at 50°C. After drying, sediments for each size fraction were taken in a marked beaker for the density separation.

2.4. Density separation using $ZnCl_2$

Zinc chloride ($ZnCl_2$) solution was used for density separation of MPs. The solution of 1.5 g/cm^3 density was prepared by dissolving 1500 g of $ZnCl_2$ into 1 L (final volume) of distilled water in a laminar flow hood to avoid air contamination. This was then poured into the samples and rigorously stirred for 40 seconds. Samples were then left untouched until all the sediments settled at the bottom. The supernatant containing floating MPs was then allowed to overflow into a petri dish by the addition of fresh $ZnCl_2$. To improve extraction efficiency and minimize particle loss, two consecutive density separation cycles were conducted for each sediment sample, and the supernatants from both cycles were then combined before analysis. The particles separated via this method were then transferred to a clean petri dish, covered, and oven-dried at 37°C for 48 hours. The selected density was considered sufficient to float common polymers such as PE, PP, PS, and a substantial proportion of PET and PA particles, while allowing efficient separation from the mineral sediment matrix.

2.5. Morphological Identification, Quantification, and Chemical Analysis of MPs

The isolated particles from all size fractions were visually identified based on their physical characteristics and quantified carefully under a light microscope (Leica S9i, Leica Microsystems) as proposed in the literature. The particles were sorted mainly by their sizes as well as two main shapes, i.e., fragments and fibers. Since the accuracy and effectiveness of visual identification in extremely small MPs can be unreliable (Balestra & Bellopede, 2022), particles smaller than 0.15 mm were not taken into consideration, as they are also difficult to handle. Quantification of MPs was done by counting the number of identifiable particles for each size fraction. Replicate samples were treated as within-site subsamples since collection was done only at one location per river, and statistical comparisons reflect variability among sampling sites rather than independent river-scale units.

In addition, several MP particles of different shapes were selected randomly, and their surface characteristics were analyzed using a scanning electron microscope (SEM; Hitachi TM 4000 Plus). MPs were placed on a carbon tape on a metal stub and then coated with gold using an ion sputter MC1000 for 15 minutes and viewed under a Scanning Electron Microscope (HITACHI TM4000Plus) at 15 kV.

To determine the polymer composition of isolated MPs, 20 particles (5 from each sampling location) from the 0.5 to 0.1 mm range were randomly selected for Fourier transform infrared spectroscopy (FTIR) analysis. Functional group identification was done using a Bruker 3000 Hyperion FTIR spectrometer (Germany) between 400 and 4000 cm^{-1}, and samples were recorded on OPUS software. Spectra analysis was done using comparison to frequently applied polymer libraries that have been used in other studies (Karing et al. 2023). Five MPs could not be conclusively identified as a result of weak spectra.

2.6. Contamination Control

To prevent secondary plastic contamination via laboratory equipment, sample collection, processing, and separation were done using only metal tools or glassware, which were cleaned with filtered water before use. All glassware used was covered in aluminum foil before sample loading. Samples collected were covered with aluminum foil during transportation to keep out any foreign particles. Contamination was avoided in the laboratory by the use of cotton lab coats and nitrile gloves, and workspaces were cleaned thoroughly with ethanol. Use of plasticware was avoided during any handling of the samples. However, procedural laboratory blanks, field blanks, and airborne fallout controls were not included in the present study, and therefore, no quantitative contamination correction was applied to the results reported for MP abundances.

2.7. Statistical Analysis

MP abundance was quantified using replicate samples (n=3) for all four rivers across five particle-size ranges. The statistical analyses were performed using GraphPad Prism and expressed as mean ± SD (standard deviation). The conformity of variables with the normal distribution and homogeneity of variance were examined using the Shapiro–Wilk normality test and the Levene test, respectively. All the quantitative data were analyzed using One-way analysis of variance (ANOVA) followed by the Tukey test with a significance level set at $p < 0.05$. Descriptive statistics (mean, SD, and 95% CI) were calculated for each river × size-class combination. Confidence intervals were computed using the formula:

$$CI_{95} = t_{0.975,df=2} \times \frac{SD}{\sqrt{3}}$$

Total MP abundance per river and overall pooled statistics were calculated from summed replicate counts.

3. RESULTS

From the analysis, MPs of assorted sizes were detected in the sediment samples of all rivers under study, with varying quantities found in each river. The abundance of MPs of all size ranges was determined as particles per kilogram of sediment.

3.1. MP Abundance

In the study, MP particles isolated from each selected site at the four rivers were found to vary in quantity depending on their size fractions, with a mean abundance of 238.17 ± 46.95 particles/kg of sediment (average ± standard deviation) with a 95% CI of ± 29.80 particles, which highlights a moderate variability among sampling sites overall. The number and abundance of MPs per sample are given in Fig. 3.

Mean abundances of MPs from each site of the four rivers differed considerably, with the highest number of MPs detected in Chite sediments (287 ± 43.41 particles), which could be attributed to the close distance to urban areas and the excessive levels of plastic pollution. Studies have also shown a positive correlation between the proximity of freshwater bodies to urban areas and elevated levels of MPs (Wang et al. 2017, Ramaremisa et al. 2022). This was followed by Tlawng (243 ± 51.12) and Tuirial (231.67 ± 16.20). Serlui-A (191 ± 18.52) was found to have the lowest

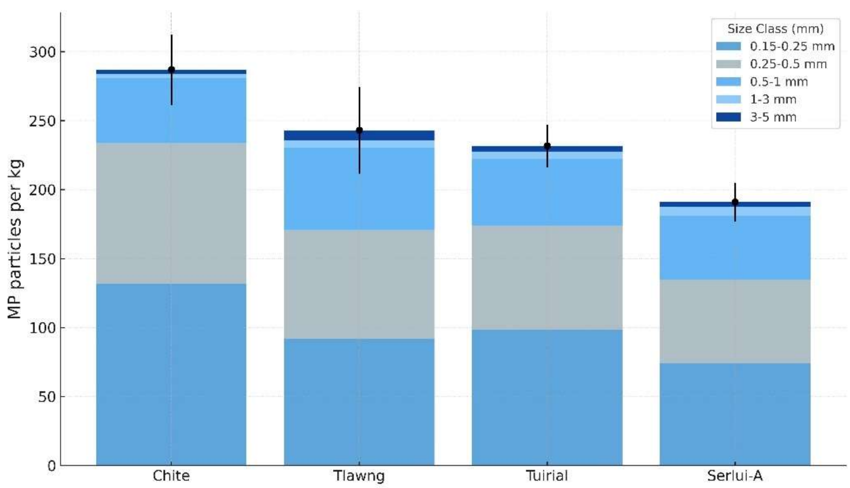

Fig. 3: Graphical representation of the number of MPs in Chite, Tlawng, Serlui-A, and Tuirial.

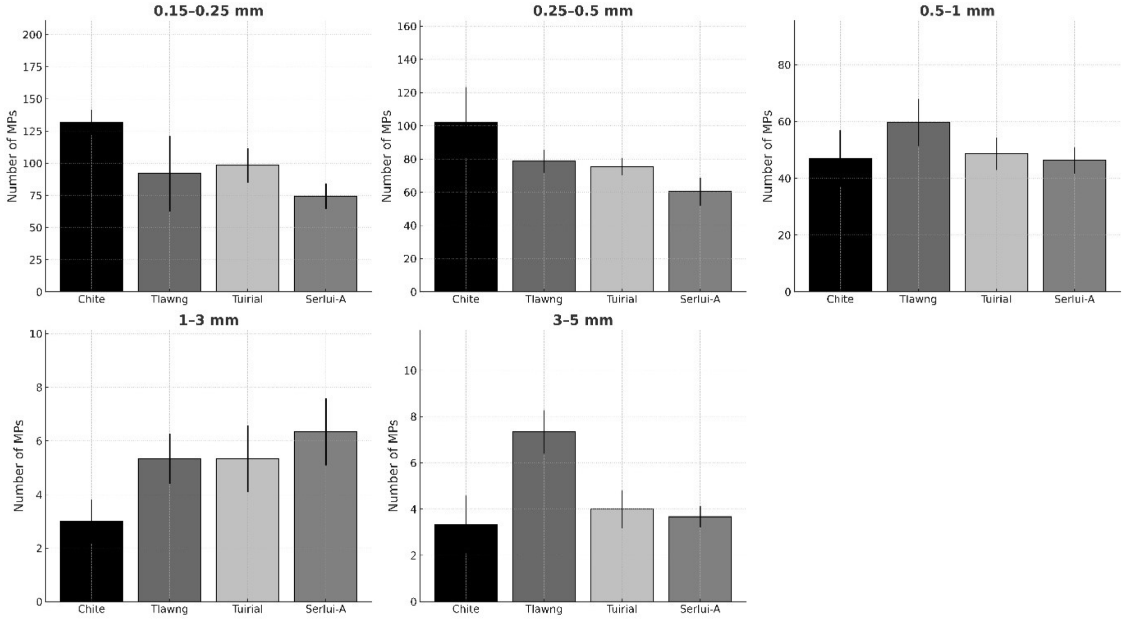

Fig. 4: Statistical analysis of the abundance of different MP sizes collected from different sampling sites.

number of MP numbers, which could be inferred as a result of its furthest distance from Aizawl compared to the other rivers. Although these differences show a clear numerical gradient, pairwise statistical analysis revealed that only the difference between Chite and Serlui-A was statistically significant (Welch's t-test: $t = 3.52$, $df = 2.70$, $p = 0.0457$; equivalent to $F(1, 2.70) = 12.41$). Differences in abundance among the remaining sampling sites were not statistically significant ($p > 0.05$).

3.2. MP Size

To evaluate variation across the different particle-size classes, one-way ANOVA was performed for each size group (Fig. 4). Isolated MPs were then analyzed down to a minimum detectable size of ≥0.15 mm, determined by the smallest size of the sieve used for separation, and particles smaller than this threshold were not quantified.

In addition, comparison of MP abundance of the different size groups across the four rivers revealed that the smallest 0.15–0.25 mm fraction displayed the highest mean counts in all sample sites, with the greatest abundance (131.67 particles) in Chite, followed by Tuirial (98.33), Tlawng (92.00), and Serlui-A (74.33). In terms of percentage, this size class accounted for 45.9% in Chite, 37.9% in Tlawng, 42.5% in Tuirial, and 38.9% in Serlui-A (Fig. 5). However, one-way ANOVA indicated that differences among rivers for this size class were not statistically significant ($p > 0.05$). The second most abundant fraction was the 0.25-0.5 mm group, contributing between 31-36%, with the highest mean (102.00 particles) present in Chite. No significant spatial variation was detected for this size fraction across the sites (one-way ANOVA, $p > 0.05$). The 0.5-1 mm group was found to be moderately abundant, ranging from 46–60 particles between the four rivers, contributing 16.4% (Chite), 24.6% (Tlawng), 21.0% (Tuirial), and 24.3% (Serlui-A) of total counts, with no statistically significant differences among rivers ($p > 0.05$). The larger groups (1-3 mm and 3–5 mm sizes) presented a very small proportion of total particles, typically below 5% of each river's MP count, both contributing approximately between 1% and 3%, depending on the river. Significant differences among sampling sites were observed only for the 3–5 mm fraction as revealed by one-way ANOVA (F(3, df□) = F-value, $p = 0.0079$). From these results, it can be observed that although overall MP loads differ between the sample sites of the four rivers, spatial variability is most pronounced in the larger-sized particles.

Overall, these results determine a clear numerical dominance of smaller-sized MPs across all sampling sites, suggesting extensive fragmentation processes within these freshwater systems. However, statistically significant spatial differences were size-class dependent and restricted to the largest particle fraction, and therefore limit broader spatial interpretations.

3.3. MP Shapes

MPs of varying shapes and structures were found in all the rivers. Fibers and fragment MPs were observed in all rivers. Fibers were the dominant shapes in all the sample

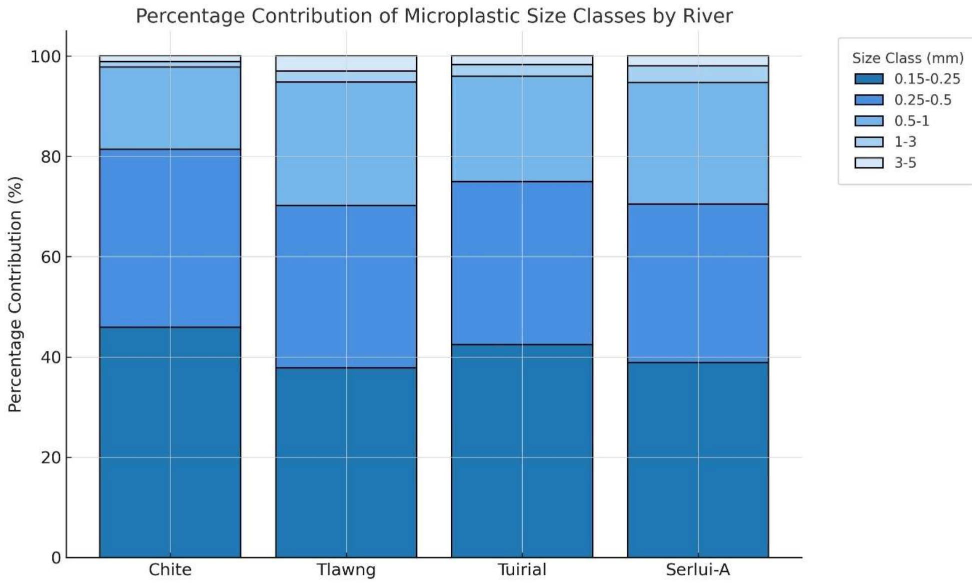

Fig. 5: Percentage contribution of MP size classes by river.

sites, accounting for approximately 40% of the total MPs recovered. Fragments and films together constituted approximately 45% of the particles, followed by spherical and foam structures (~10%). It also needs to be stated that shape-based categorization was derived from visual inspection, and therefore, minor classification uncertainty cannot be excluded, particularly for irregular or weathered particles. Accordingly, the reported shape proportions need to be inferred as indicative trends rather than definitive morphological distributions.

The detailed distribution of various shapes identified from the samples is given in Fig. 6.

The high abundance of fiber types in this study corroborates several other reports that have found MFs to be the dominant shape in freshwater bodies and sediments (Wang et al. 2017, Xu et al. 2021, Priya et al. 2023, Hosseinpour et al. 2025). Microscopic images of MPs comprising different size ranges, shapes, and colors are given in Fig. 7 and Fig. 8.

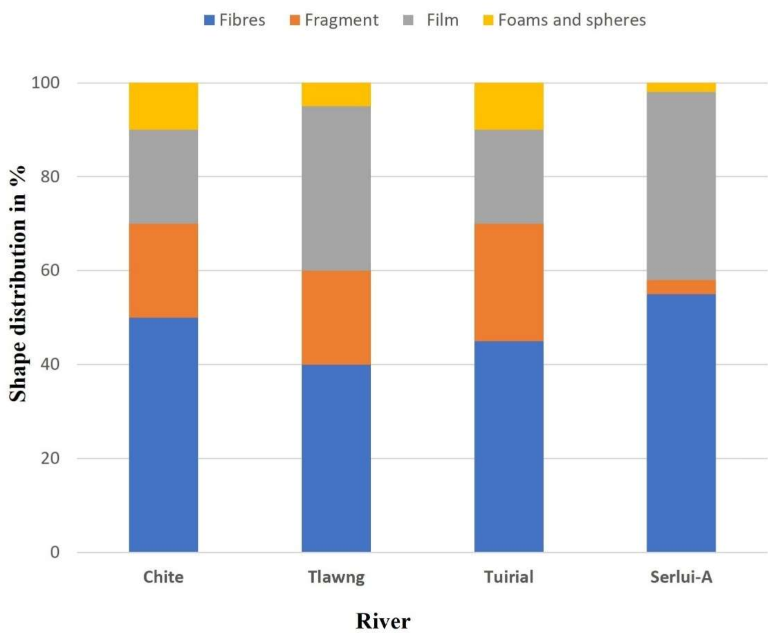

Fig. 6: Distribution of various MP shapes identified from sediment samples.

3.4. Surface Morphology and Chemical Characteristics

SEM analysis of different shapes of MPs (Fig. 9, A-D) showed variations in their surface morphologies, illustrating the heterogeneity in shape, texture, and surface characteristics typically associated with environmentally weathered polymers. The surfaces of fragments were observed to be uneven, rough, and cracked, suggesting exposure to weathering, abrasion, and disintegration over a period of time. Fig. 9-A, C, D show irregular, angular plastic fragment shapes with cracked surfaces and angular edges. Fig. 9-B displays an intertwined, flexible fiber shape with smooth surfaces that are typically associated with anthropogenic textile sources.

FTIR analysis was done on 20 isolated particles (5 from each river within the 0.5-1 mm size groups) that were randomly selected for polymer identification to validate visual identification. Spectral matching was conducted against a reference library, and particles were classified as MPs only when a match similarity of ≥70% was obtained, a threshold commonly adopted in environmental MP studies. Out of these, 75% (15 out of 20 particles) were thus confirmed to be MPs. Five samples could not be accurately identified due to inadequate spectrum intensity, which may imply a potential degree of overestimation associated with visual sorting alone. Therefore, polymer identification should be considered preliminary, and abundance values derived from visual inspection may include a limited proportion of non-plastic particles. The ≥70% match similarity threshold was selected as per established MP FTIR studies, acknowledging that environmental degradation and surface fouling can lower spectral similarity scores without changing the underlying polymer identity. From this analysis, two distinct types of polymers, namely, Polyethylene (PE) and Polypropylene (PP), were identified (Fig. 10), with PE making up the majority of the polymers (93%) from the selected and analyzed samples. Spectra identifying PE showed two prominent aliphatic C–H stretching vibrations at ~2916 cm^{-1}

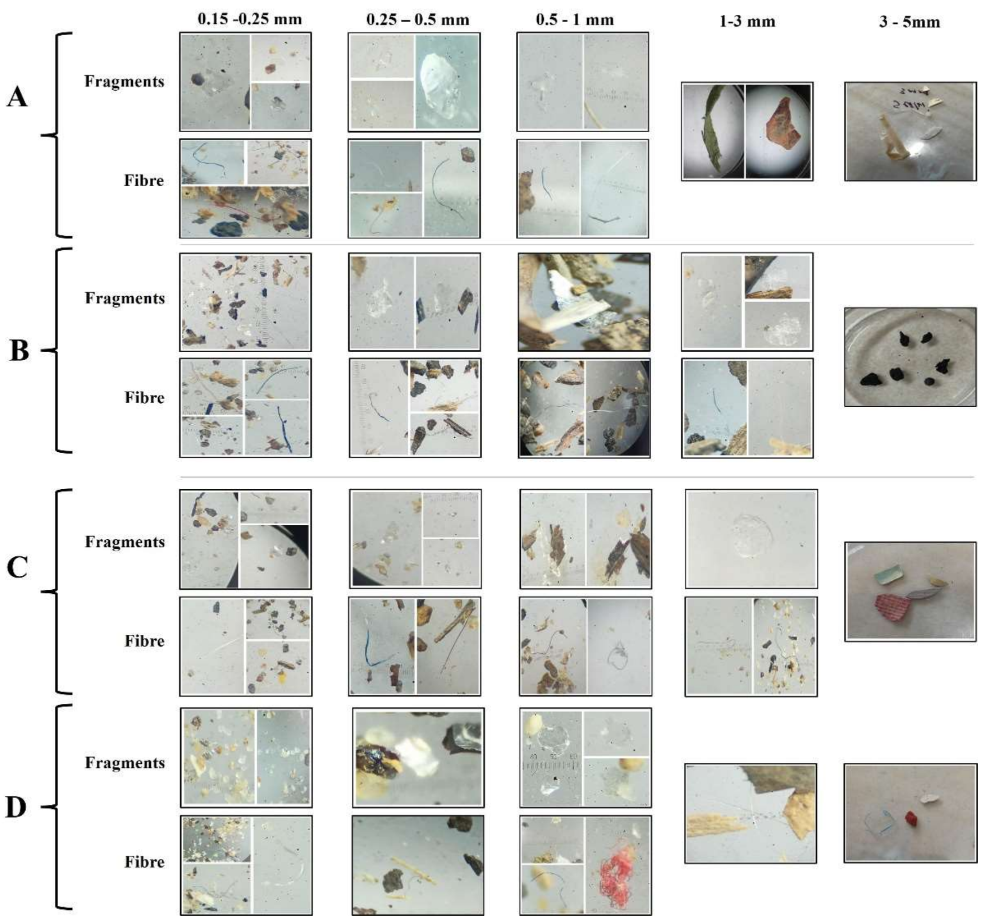

Fig. 7: Photographs of different MPs (fragments and fibers) isolated from sediment samples, with their size observed under a light microscope (10X and 40X magnifications). (A) MPs found in the Chite River. (B) MPs found in Tlawng. (C) MPs found in Serlui-A. (D) MPs found in Tuirial.

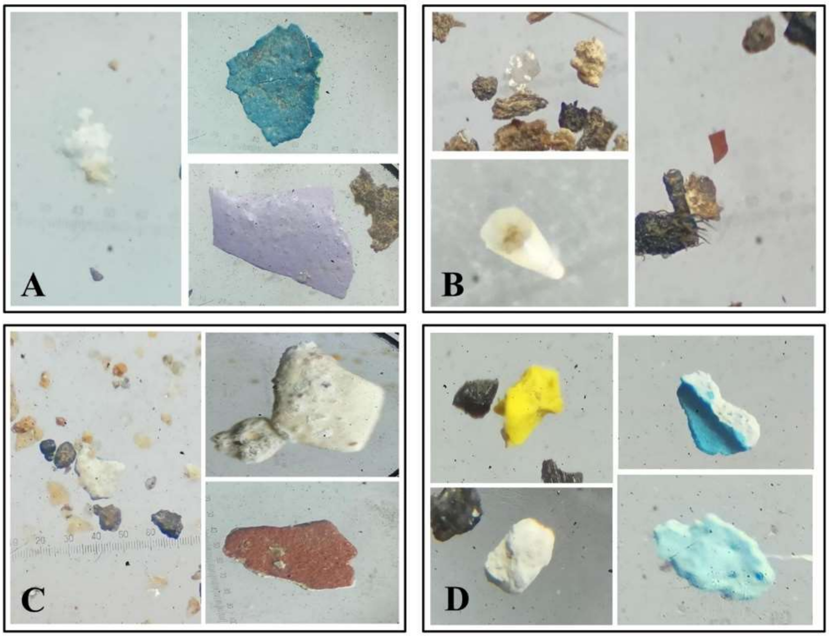

Fig. 8: Additional photographs of different MPs found in different rivers (A) MPs found in the Chite River. (B) MPs found in Tlawng. (C) MPs found in Serlui-A. (D) MPs found in Tuirial.

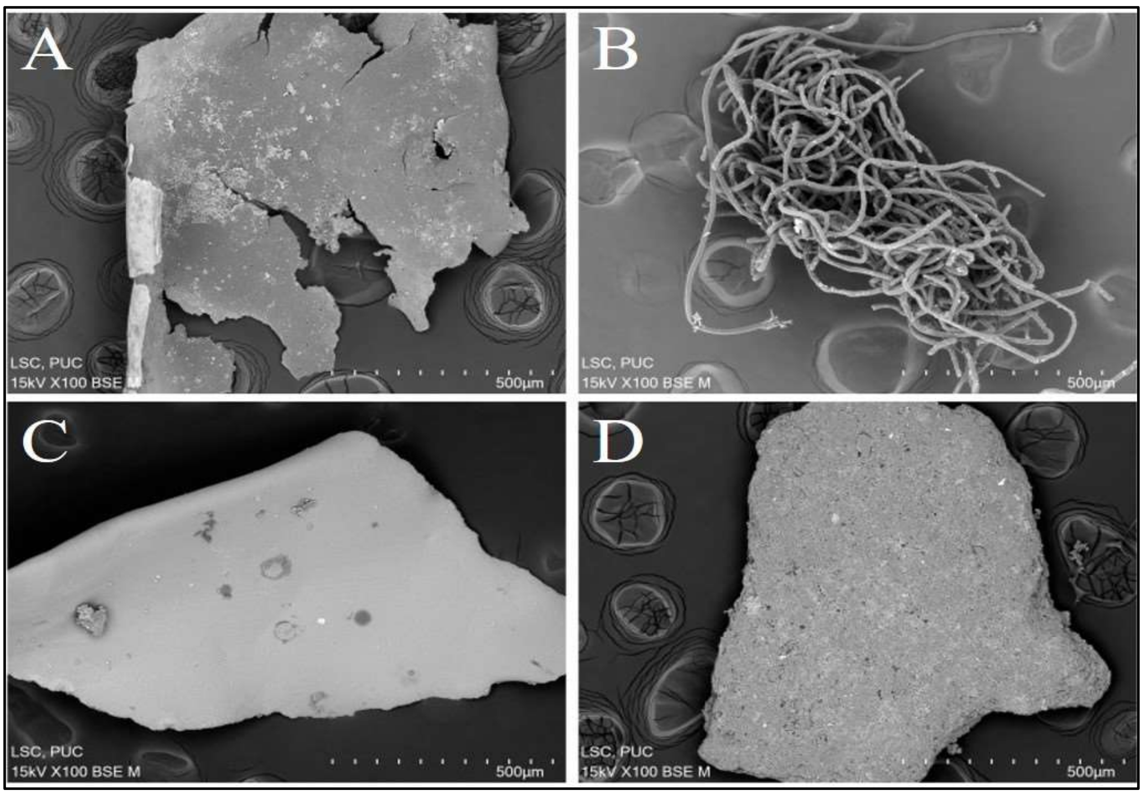

Fig. 9: SEM image of different MPs captured at 15 kV at 100 magnification. (A, C, D) Fragments (B) Fibers.

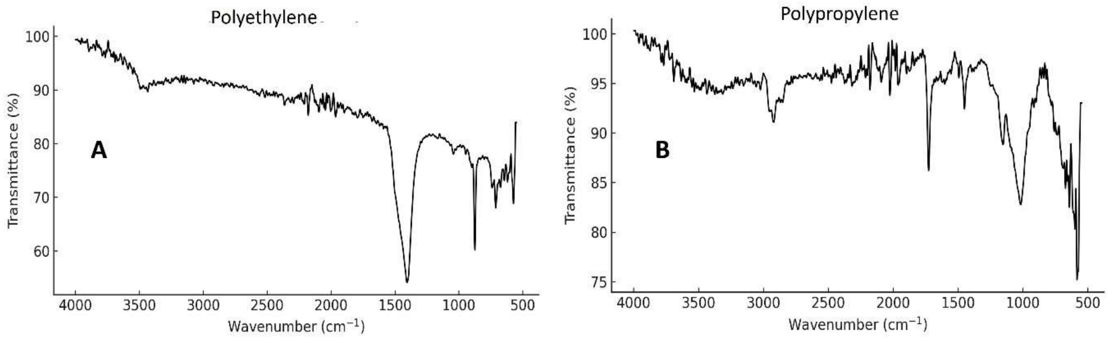

Fig. 10: FTIR spectra of MPs identified as Polyethylene (A) and Polypropylene (B).

(asymmetric CH_2 stretch) and ~2848 cm^{-1} (symmetric CH_2 stretch), accompanied by strong CH_2 deformation bands at ~1470 cm^{-1} (scissoring) and ~1463 cm^{-1} (bending). The most definitive marker of PE, i.e., the CH_2 rocking vibration near ~720 cm^{-1}, was consistently present across all PE samples. The absence of carbonyl (C=O), aromatic (C=C), or halogen-containing (C–Cl) functional groups further supported the classification of these particles as PE. indicating a potential degree of overestimation associated with visual sorting alone. Therefore, polymer identification in the present study should be considered preliminary, and abundance values derived from visual inspection may include a limited proportion of non-plastic particles.

Spectra identification for PP showed a strong CH_3 symmetric bending vibration at ~1376 cm^{-1}, which serves as the primary indicator of PP. Additional CH_2 and CH_3 deformation modes were observed at ~1455 cm^{-1}, along with C–H stretching vibrations at ~2950–2838 cm^{-1}. The presence of skeletal C–C stretching and CH wagging modes in the 1165–997 cm^{-1} region, together with an isotactic PP band near ~840 cm^{-1}, further confirmed the identity of the PP polymer.

4. DISCUSSION

This study aimed to evaluate the extent of MP pollution in the shore sediments of rivers close to Aizawl city, Mizoram. The state lies in the north-eastern part of India and is situated in the lower eastern Himalayan region. Assessment results showed mean MP abundance to be 238.17 ± 46.95 particles/kg, and found to be highest in rivers that are relatively closer to Aizawl municipality, i.e., the Chite river with the maximum number of MP particles, followed by the Tlawng river. This corroborates various studies that have established a positive correlation between elevated MP abundance and proximity of a freshwater body to urban and community areas (Peng et al., 2018; Tibbetts et al. 2018, Kongkamee et al. 2024). However, it is critical to note that the interpretations presented in this study are site-specific rather than river-wide, as each river sediment was represented by a single sampling location and replicate samples (n = 3) constituted within-site subsamples as opposed to independent spatial replicates. Considering pronounced spatial heterogeneity characteristics for different riverine systems, the detected differences in MP abundance among the sampled locations should therefore be interpreted in light of the study's spatial limitations. Consequently, statistical comparisons among the four rivers also reflect relative differences only at the sampled sites and do not infer whole-river contamination patterns. While higher MP abundances were observed at sites in closer proximity to urbanized areas, these patterns should be considered indicative and exploratory, unless further established through multi-site, longitudinal, and seasonal sampling designs that can effectively resolve river-scale spatial variability. Additionally, the mean abundance of MPs in the shoreline sediments of other rivers in different parts of the Himalayas varies greatly. Table 2 gives a glimpse of the various studies that have been conducted on MP pollution in different rivers within the Himalayan region and lists the mean abundance and types of polymers that have been detected. Values have been presented using original units (items/kg for sediments; items/L or items/m^3 for water) from the published articles and categorized by sample matrix. The comparisons across studies are qualitative only, since the evident differences in units, sampling strategies, and analytical methods prevent direct numerical comparison.

Unchecked pollution is still rampant in urban settlements, where domestic wastes are being discarded illicitly in side drains and open areas. Consequently, these are then carried off into rivers by wind and rainwater, and are further broken down into MPs via weathering. Although the Tuirial River is the farthest in distance from Aizawl, MP counts were higher than those of Serlui-A, which runs slightly closer to Aizawl. This could be attributed to its proximity to the rural settlement of Tuirial village around the Tuirial River. As a result, anthropogenic activities such as mismanagement

Table 2: List of studies on MP pollution in sediments and water of other rivers of the Himalayan region, with mean abundances and polymer types.

	Rivers	Sample	Abundance	Major MPs	Reference
Western Himalayan rivers	Indus	Sediment	525-1752 MP/kg	PP, PE, PES	Tsering et al. 2021
	Beas River	Water	46-222 items/L	PE	Bhaduri et al. 2025
		Sediment	36-896 items/kg		
	Chenab River	Water	34.66-45.98 MPs/m^3	PET, PP	Hafeez et al. 2023
	River Yamuna	Water	500-3900 MPs/m^3	PE, PS, PP	Vaid et al. 2022
	Ravi river	Water	768-1324 MPs/m^3	PP, PE, PES, and PS	Aslam et al. 2022
	Sutlej River	Water	3.6-19.0 MPs/L	PP, HDPE, PET	Nagendra et al. 2025
	Soan River	Water	132.7-641.3 items/m^3	PET, PP, PE.	Jabeen et al. 2023
Central Himalayan Rivers	River Ganga	Water	118.5 ± 49.65 particles /1000 L	PE, PP	Badola et al. 2023
		Sediment	131.5 ± 53.60 particles/kg		
	Upper Himalayan Ganga River	Water	100-1550 particles/L	PE, PA, PS	Chaudhary et al. 2025
		Sediment	50-1300 particles/Kg		
	River Ganga - (Suswa, Bindal and Rispana)	Water	2800-4200 items/L	PE, PP	Nayal & Suthar 2022
		Sediment	7200-16,400 items/kg		
	Karnali River	Water	0.12-0.64 particles/L	PE, PP	Maharjan et al. 2025
	Sapta-Gandaki river system	Water	24.7-61.2 particles/L	PE, PET, PVC	Kandel et al. 2025
	Kosi river	Water	50-325 items/m^3	PE, PET, PA	Yang et al. 2021
		Sediment	15-120 items/kg		
Eastern Himalayan Rivers	Brahmaputra	Sediment	531-3485 MP/kg	PP, PE, PA	Tsering et al. 2021
	Yarlung Tsangpo	Water	728.26 ± 100.53 items/m^3	PP, PE	Li et al. 2024
		Sediment	43.16 ± 5.82 items/kg		
	Lower Brahmaputra River	Water	11-32 MPs/L	Nylon, PET, PP	Hassan et al. 2025
	Manas river	Water	10-22 items/L	PP, PET, PS	Wang et al. 2021
	Jia Bharali River	Water	22.35-27.94 MPs/L	PE, PP	Lahon & Handique 2024
		Sediment	19.42-29 MPs/kg		
	Lasha river	Water	0.63 n/L	PP, PE	Zhou et al. 2023
		Sediment	0.37 n/g		
	Kaljani River	Water	0.14 ± 0.11 pieces m^{-3}	PE, nylon, PP	Goswami et al. 2024
	Karnaphuli River	Water	14.24 - 26.68 items m^{-3}	PET, HDPE, acrylonitrile butadiene styrene (ABS)	Jui et al. 2025

and dumping of garbage from the village, either directly or indirectly, into the river, the ongoing construction of roads, and a football field may have contributed to the elevated level of MPs in this river.

A considerable number of MPs were also detected in Serlui-A, which has various tributaries in the form of small streams, non-perennial brooks, and gullies that originate from areas close to Aizawl municipality. Further, the presence of Li Cheng (or Dilmawi, a type of stream pool), which is a tourist attraction in Serlui-A, could possibly be a key contributor to MPs in this river, due to the indiscriminate disposal of plastic garbage by visitors. Although the MP count in Serlui-A is the lowest when compared to other observed rivers, their detection in this river is particularly concerning because drinking water for the Aizawl municipal areas is sourced from this river. However, since no studies on MP pollution in freshwater bodies within the state have been conducted as yet, conclusions cannot be made regarding the presence and abundance of MPs in the water, but further studies are tremendously warranted. Since Mizoram does not have large-scale manufacturing industries and complexes, the aggregation of MPs in the shore sediments of these rivers can mostly be attributed to inadequate domestic waste management procedures in the urban areas and their subsequent runoff into surrounding water bodies and non-target areas due to the hilly terrain and high annual rainfall (Singh et al. 2023). These garbage masses are then evidently weathered down and fragmented into minuscule particles by various natural elements and environmental factors. Sediments eventually act as sinks for MP deposition, with gradual aggregation over time since they can easily be carried over long distances due to their minuscule sizes and lower densities (Ismanto et al. 2023, Napper et al. 2023).

The study found a higher abundance of smaller MPs below 1mm, especially within the size ranges of 0.15-0.25 mm and 0.25-0.5 mm in all four sampling locations, while those above 3mm in size were significantly lower. Fragmentation processes contribute significantly to the size distribution of MPs in aquatic systems and tend to settle more easily due to their reduced buoyancy and greater susceptibility to deposition under lower energy conditions (Browne et al. 2011). Larger plastic items break down into smaller particles as a result of physical, chemical, and biological factors, and this continued weathering may explain why smaller MPs are found in higher concentrations in sediments (Wang et al. 2022, Lu et al. 2023). Research by Klein et al. (2015) on the Rhine River revealed that the majority of MPs in sediments were smaller than 1 mm, with finer-grained sediments harboring the highest concentrations of MPs. Similarly, a review by Yang et al. (2021) observed that in river systems, smaller MPs are usually more abundant than larger ones in sediments, and MPs less than 0.5mm in particular were especially prevalent in sediment samples, further supporting the notion that smaller particles are more likely to accumulate in sediments due to their lower transport potential and easier incorporation into sediment layers. Another study by Ramaremisa et al. (2022) also reported a decrease in abundance with an increase in MP sizes in sediments of the Vaal River in South Africa. In addition, other factors may also contribute to the abundance of MPs in sediments. Waldschläger and Schüttrumpf (2019) demonstrated that hydrodynamic conditions such as current velocity and turbulence significantly affect the settling velocities of MPs. Smaller particles settle more quickly due to reduced drag and hydrodynamic resistance, accumulating in riverbeds, especially in regions of decreased water flow such as oxbow lakes and estuaries, implying that the smaller the particles, the greater the likelihood of their being present in river sediments. Although numerical differences in MP abundance were observed among rivers, particularly higher counts in Chite compared to the other sites, most size classes did not exhibit statistically significant spatial variation, which may suggest a broadly comparable distribution of smaller MPs across the river network. Statistical analyses demonstrated that spatial differences were size-dependent, with significant variation detected only in the largest particle fraction (3–5 mm). These results imply that larger particles may be more strongly influenced by localized sources, limited transport potential, and site-specific retention mechanisms, whereas smaller particles are more uniformly dispersed due to enhanced mobility and fragmentation. Since the analytical detection limit of this study was limited to ≥0.15 mm, MPs smaller than this threshold were not captured, and the reported abundances potentially underestimate the contribution of smaller size fractions, particularly fine fragments and fibers below 0.15 mm.

Fibers represented the majority of MP particles in all the rivers under study, constituting more than 40% of all MPs isolated. This corroborated other studies on freshwater bodies in other Indian river systems where MFs were the dominant type (Kalangutkar et al. 2023, Napper et al. 2023), as well as sediments of several rivers in other parts of the globe (Huang et al. 2021, Akdogan et al. 2023). Domestic and commercial laundering of various types of textiles has been known to be a significant contributor to MFs in different aquatic bodies and is also a consequence of proximity to urban areas (Hazlehurst et al. 2023). Therefore, household wastes from residents of the city, including effluents from washing textiles, have possibly added to the abundance of MFs in the observed river sediments. Blue, red, and transparent fibers were the main MFs found in the sediment samples. The transparent fibers may indicate that fishing does contribute in some measure to the abundance of MFs in these rivers, as net fishing is common in some parts of the selected rivers, especially Tlawng. However, given that fibers constituted a significant proportion of the detected MPs, the absence of procedural blanks is recognized as a limitation of the present study. Since fibers can be particularly sensitive to airborne contamination during sampling and laboratory processing, stringent precautions were applied to the best extent possible during sample collection, handling, and analysis to minimize external contamination. In the absence of field or laboratory blanks, a quantitative assessment of background contamination was not feasible, and therefore the reported fiber abundances should be appropriately interpreted, as minor contributions from secondary contamination cannot be fully ruled out.

Of the 20 particles selected for FTIR analysis from the visually identified MPs, 15 particles (75%) were spectroscopically confirmed as plastic polymers, while the remaining five particles could not be reliably identified due to insufficient spectral quality and were therefore excluded from polymer classification. Consequently, polymer composition results are based solely on this subset of confirmed particles.

Although visual microscopy remains a widely applied screening approach in MP studies, particularly for larger size fractions, the absence of auxiliary confirmation techniques such as hot needle testing, Nile Red staining, etc., represents a limitation of the present study, and as a result, classification uncertainty cannot be fully excluded. Nevertheless, PE was found to be the dominant type of polymer, which underscores the pervasive use of PE-based materials in the region under study. PE is the primary constituent of various plastic products such as single-use packaging films, carry bags, wrappers, and household consumables, all of which are extensively used and frequently mismanaged in urban and peri-urban areas (Schwab et al. 2024). Our findings substantiate several other studies in different rivers (Doyen et al. 2019, Maheswaran et al. 2022, Babkiewicz et al. 2025) and also within the Himalayan region, where PE has also been found to be one of the most abundant pollutant particles (Table 2). Comparatively, PP particles were significantly lower amongst the analyzed particles, which may be consistent with their use in more rigid consumer products such as bottle caps, storage containers, and packaging components, and their slightly higher density and mechanical strength likely reduce fragmentation rate relative to PE, possibly contributing to their lower representation in sediments (Khoironi et al. 2020, Anak Alexander Tampan et al. 2022). However, given the limited number of particles subjected to FTIR analysis, the polymer identification presented in this study is preliminary and indicative, intended to provide an overview of dominant polymer types rather than a complete characterization of sediment polymer composition. Additionally, although a $ZnCl_2$ density of 1.5 g cm^{-3} used in the isolation method enables effective recovery of most environmentally relevant polymers, it is acknowledged that some high-density polymers (e.g., PVC and highly compact or mineral-encrusted PET particles) may not be fully recovered, particularly when aging, biofouling, or aggregation can increase their effective density. Despite the use of two sequential extraction cycles, a degree of underestimation of high-density MPs cannot be entirely excluded. Hence, the reported polymer composition should therefore be interpreted as conservative with respect to dense polymer fractions.

5. CONCLUSIONS

This study provides a preliminary and baseline assessment of MP contamination in shoreline sediments of rivers that run close to Aizawl city, the most urbanized region in the state of Mizoram. Importantly, this study presents one of the first systematic efforts to document MP contamination in site-specific freshwater riverine sediments from this part of the Eastern Himalayan region. Baseline information on MPs pollution in Mizoram has been virtually absent, despite the region being recognized as a biodiversity hotspot with ecologically sensitive river systems. By providing the first empirical evidence of MP occurrence in riverbank sediments in and close to Aizawl, the present work fills a critical knowledge gap and establishes a reference point for future monitoring and comparative assessments. Such baseline data are essential for the early detection of emerging pollutants, formulation of region-specific management strategies, and prevention of further degradation of freshwater ecosystems in this fragile Himalayan landscape. Within the constraints of the study design, sampling coverage, and analytical resolution, this study also paints a harrowing picture of the extensive use and improper management of plastic products in Aizawl at large, since these are evidently polluting the rivers in proximity to urban areas and settlements. More in-depth research concerning MP pollution is crucial to detect the presence and extent of contamination in air, soil, food, and other water bodies within the state, since they are also susceptible to pollution from source to distant sites via river systems. Although the lack of funding for this study has limited our preliminary investigation in terms of area of study, sample type, and chemical analysis of particles, further studies on concentrations in river water and ingestion by aquatic organisms are still lacking and are of utmost importance. In particular, tap water from Serlui-A needs further investigation for MP presence since it is a critical lifeline for thousands of people. However, the present study did not analyze drinking water samples and did not evaluate human exposure or health risk. Moreover, according to the World Health Organization, there are currently no universally accepted numeric safety thresholds for MPs in water, and regulatory and scientific bodies recommend enhanced monitoring and further toxicological research before such standards can be established (WHO, 2019). Nevertheless, the detected occurrence of MPs in riverine environments highlights the need for future integrated studies that include drinking water analysis, exposure assessment, and toxicological evaluation to better understand potential human health implications. Such investigations would be crucial for translating such findings into meaningful risk assessments.

Furthermore, there is a need for strengthened management strategies to limit the extensive use and disposal of plastics to minimize the indiscriminate pollution of our precious rivers, not just for the sake of humans, but for all organisms associated with these aquatic environments. Single-use plastic bags, bottles, and packaging items should ideally be substituted with natural fiber products that are produced from bamboo, jute, cotton, etc. Although plastic pollution is a global issue, the state of Mizoram also still has a long way to go in terms of combatting it, with an urgent need to provide alternatives to single-use plastics and more efficient facilities for plastic recycling. In addition, collective awareness amongst the people needs to be inculcated regarding the harmful consequences of pollution on the environment and the importance of mitigating pollution as a whole.

6. ABBREVIATIONS

ABS:	acrylonitrile butadiene styrene
HD/LD-PE:	high-and low-density polyethylene
MFs:	Microplastic fibers
MPs:	Microplastics
PA:	Polyamide
PE:	Polyethylene
PES:	Polyester
PET:	Polyethylene terephthalate
PS:	Polystyrene
PP:	Polypropylene
PVC:	polyvinyl chloride
SEM:	Scanning Electron Microscope

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