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Spatial Distribution of Microplastic Abundance and Characteristics in the Surface Water of the Kahayan River, Central Kalimantan

Normila Normila[1*], Resna Maulia[1], Juni Ramadhani[1]

[1] Poltekkes Kemenkes Palangka Raya, Palangka Raya, Kalimantan Tengah, Indonesia

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A B S T R A C T

Microplastic contamination in freshwater ecosystems has become a growing environmental concern due to its adverse effects on aquatic ecosystems and human health. The Kahayan River, one of the major rivers in Central Kalimantan, is widely used for water supply, transportation, and fisheries. However, information on the spatial distribution and physical characteristics of microplastics in its urban section remains limited. This study aimed to analyze differences in microplastic abundance among sampling stations and characterize the shape, size, and color of microplastics in the river's surface water. An observational biomonitoring study was conducted at four sampling stations representing different anthropogenic activities. Surface water samples were collected using a plankton net and visually identified under a stereomicroscope. Microplastic abundance among stations was analyzed using Welch's ANOVA, followed by the Games–Howell post hoc test ($\alpha = 0.05$). Microplastics were detected at all stations, with abundances ranging from 5.80 ± 0.92 to 10.33 ± 1.97 particles/L. Welch's ANOVA revealed significant differences among stations ($p = 0.035$), while the Games–Howell test identified a significant difference only between Stations T1 and T3 ($p = 0.018$). Microplastics were predominantly fibers (71.31%), with sizes of 0.501–1.000 mm (35.86%) and transparent particles (51.00%). Their distribution varied among sampling stations rather than following a linear upstream-to-downstream pattern. Local environmental conditions influence the distribution of microplastics in the Kahayan River at each sampling station. These findings provide baseline information to support microplastic monitoring and freshwater pollution management in the Kahayan River.

Kontaminasi mikroplastik di ekosistem air tawar telah menjadi perhatian lingkungan yang semakin meningkat karena dampaknya yang merugikan terhadap ekosistem perairan dan kesehatan manusia. Sungai Kahayan, salah satu sungai utama di Kalimantan Tengah, banyak dimanfaatkan untuk pasokan air, transportasi, dan perikanan. Namun, informasi tentang distribusi spasial dan karakteristik fisik mikroplastik di wilayah perkotaan masih terbatas. Studi ini bertujuan untuk menganalisis perbedaan kelimpahan mikroplastik antarstasiun pengambilan sampel serta mengkarakterisasi bentuk, ukuran, dan warna mikroplastik dalam air permukaan sungai. Studi biomonitoring observasional dilakukan di 4 stasiun pengambilan sampel yang mewakili aktivitas antropogenik yang berbeda. Sampel air permukaan dikumpulkan menggunakan jaring plankton dan diidentifikasi secara visual menggunakan mikroskop stereo. Kelimpahan mikroplastik di antara stasiun dianalisis menggunakan ANOVA Welch, diikuti oleh uji post hoc Games–Howell ($\alpha = 0{,}05$). Mikroplastik terdeteksi di semua stasiun, dengan kelimpahan berkisar antara 5,80 ± 0,92 hingga 10,33 ± 1,97 partikel/L. Analisis varians Welch (ANOVA) mengungkapkan perbedaan signifikan antartasiun ($p = 0{,}035$), sedangkan uji Games–Howell mengidentifikasi perbedaan signifikan hanya antara Stasiun T1 dan T3 ($p = 0{,}018$). Mikroplastik sebagian besar berupa serat (71,31%), dengan ukuran 0,501–1,000 mm (35,86%) dan partikel transparan (51,00%). Distribusinya bervariasi antarsasiun pengambilan sampel, bukan mengikuti pola linier dari hulu ke hilir. Kondisi lingkungan lokal memengaruhi distribusi mikroplastik di Sungai Kahayan pada setiap stasiun pengambilan sampel. Temuan ini memberikan informasi dasar untuk mendukung pemantauan mikroplastik dan pengelolaan pencemaran air tawar di Sungai Kahayan.

* Corresponding author: Normila Normila
Poltekkes Kemenkes Palangka Raya, Palangka Raya, Kalimantan Tengah, Indonesia
Email: normila@polkesraya.ac.id

1. Introduction

Plastic pollution has become one of the most pressing global environmental issues over the past few decades, driven by the continuous increase in plastic production and consumption. According to the United Nations Environment Program (UNEP), global plastic production has exceeded 400 million tonnes annually, with a substantial proportion ultimately entering the environment due to inadequate waste management practices (UNEP, 2023). Among the various forms of plastic pollution, microplastics have attracted considerable scientific attention because of their widespread occurrence and persistence in aquatic ecosystems. Microplastics are generally defined as plastic particles smaller than 5 mm that originate either from intentionally manufactured small plastic products (primary microplastics) or from the fragmentation of larger plastic debris (secondary microplastics) (Frias & Nash, 2019). Their small size facilitates dispersion throughout aquatic environments, limits natural degradation, and increases their potential to accumulate in aquatic organisms while acting as carriers of hazardous contaminants adsorbed onto their surfaces (He et al., 2024; Upadhyay et al., 2024; Zhang et al., 2024).

Rivers are among the primary pathways by which plastic debris is transported from terrestrial environments to estuaries and marine ecosystems (Barbuzano, 2019; Cai et al., 2021). Various anthropogenic activities occurring along river catchments, including residential settlements, commercial activities, transportation, industrial operations, and inadequate solid waste management, contribute substantially to the continuous input of plastic waste into freshwater systems. Once introduced into aquatic environments, plastic materials undergo physical, chemical, and biological weathering processes that progressively fragment them into microplastics (Cai et al., 2021; Li et al., 2020). Consequently, rivers function not only as transport corridors but also as important sites for the accumulation, transformation, and redistribution of microplastic particles, thereby influencing the ecological integrity and environmental quality of freshwater ecosystems (Darabi et al., 2021).

Research on microplastic contamination in Indonesian river ecosystems has expanded considerably in recent years. Numerous studies have documented the occurrence of microplastics in rivers across Indonesia, revealing substantial variation in their abundance, morphology, particle size, color, and polymer composition (Haribowo et al., 2023). Most investigations have consistently reported fibers as the dominant microplastic type, whereas smaller particles generally occur more frequently than larger ones (Salsabila et al., 2026; Sari et al., 2021). Nevertheless, the considerable variability observed among different river systems indicates that local environmental conditions and anthropogenic activities strongly influence the abundance and characteristics of microplastics.

The Kahayan River is one of the major river systems in Central Kalimantan and plays a crucial role in supporting freshwater supply, transportation, fisheries, and a wide range of socio-economic activities. Previous studies have reported the occurrence of microplastics in various environmental compartments of the Kahayan River, including surface water, sediments, and fish, while also investigating polymer composition and the relationship between sediment grain size and microplastic accumulation (Zakiah, Riani, Taryono, & Cordova, 2024; Zakiah, Riani, Taryono, Cordova, et al., 2024). These studies demonstrate that microplastics are already widely distributed throughout the river ecosystem. However, information regarding spatial variations in microplastic abundance and characteristics in surface water across multiple sampling locations remains limited. Such information is essential for establishing baseline datasets that support long-term monitoring and management of microplastic pollution. Therefore, further research specifically on the abundance and characteristics of microplastics in surface waters is required to complement existing knowledge of microplastic contamination in the Kahayan River.

The physical characteristics of microplastics, including their morphology, particle size, and color, provide valuable information for assessing the nature and extent of microplastic contamination in aquatic environments. These characteristics may help identify potential pollution sources, fragmentation processes, environmental transport mechanisms, and the environmental fate of microplastic particles. Consequently, characterization of microplastics not only complements abundance data but also provides a more comprehensive understanding of microplastic pollution within river ecosystems (Hartmann et al., 2019; Li et al., 2023).

Therefore, this study aimed to evaluate the abundance and characterize the morphology, size, and color of microplastics in the surface water of the Kahayan River, Central Kalimantan. The findings are expected to complement existing knowledge of microplastic contamination in the Kahayan River and provide baseline information for future research and long-term freshwater environmental monitoring programs.

2. Methods

2.1. Study Area and Research Design

This study employed a quantitative field survey approach to investigate the abundance and characteristics of microplastics in the surface water of the Kahayan River, Central Kalimantan, Indonesia. Surface water samples were collected from four sampling stations representing different levels of anthropogenic activities along the river. The collected samples were subsequently analyzed in the laboratory to determine microplastic abundance and characterize their morphology, size, and color.

The study was conducted along the Kahayan River within the administrative area of Palangka Raya City, Central Kalimantan Province, Indonesia. Four sampling stations were selected through purposive sampling to represent different environmental settings and varying intensities of human activity along the river corridor. The geographic coordinates of each sampling station are presented in Table 1.

Table 1. Sampling geographic coordinates

Station	Geographic coordinates
T1	2.19687° S; 113.93196° E
T2	2.20299° S; 113.92061° E
T3	2.20565° S; 113.92869° E
T4	2.20370° S; 113.94016° E

2.2 Sample Collection and Laboratory Analysis

Surface water sampling was conducted during the rainy season in September 2025. The rainy season was selected because increased surface runoff is expected to transport larger quantities of plastic waste from residential and urban areas into the river, thereby increasing the likelihood of detecting microplastic contamination.

Surface water samples were collected using a plankton net with a mesh size of 300 µm and a mouth diameter of 20 cm. At each sampling station, three independent samples (triplicate sampling) were collected to improve the representativeness of microplastic abundance estimates.

Sampling was performed along the riverbank by horizontally towing the plankton net across the water surface over a predetermined distance. Upon completion of sampling, the cod end of the plankton net was carefully opened, and the retained material was transferred directly into labeled sample bottles without additional rinsing to minimize the potential loss of microplastic particles. All samples were immediately labeled according to their respective sampling stations and transported to the laboratory for further analysis.

Laboratory analysis followed established procedures for the visual identification of microplastics in freshwater samples. Prior to microscopic examination, samples underwent laboratory preparation procedures in accordance with standard operating protocols to obtain residues containing potential microplastic particles.

The recovered particles were examined under a stereomicroscope for visual identification and characterization. Morphological characteristics classified microplastics into two major categories: fibers and fragments. The number of particles in each category was manually counted and subsequently expressed as microplastic abundance in units of particles L^{-1}. In addition to morphology, particle size and color were also recorded based on laboratory observations.

2.3. Statistical Analysis

Microplastic abundance was expressed as the mean ± standard deviation (SD). Data normality was assessed using the Shapiro–Wilk test, whereas homogeneity of variances among sampling stations was evaluated using Levene's test.

The normality test indicated that the data were normally distributed, whereas Levene's test revealed unequal variances among groups. Therefore, differences in microplastic abundance among sampling stations were analyzed using Welch's analysis of variance (Welch's ANOVA), which is more robust than conventional one-way ANOVA when the assumption of homogeneity of variances is violated.

When significant differences were detected, pairwise comparisons were performed using the Games–Howell post hoc test. All statistical analyses were conducted using IBM SPSS Statistics version 27, with statistical significance defined at $p < 0.05$.

3. Results

The This study was conducted at four sampling stations distributed along the Kahayan River in Palangka Raya City, Central Kalimantan, Indonesia. The stations were selected to represent different environmental settings and anthropogenic activities along the river, thereby allowing an assessment of the spatial distribution of microplastics in surface water. The locations of the sampling stations are presented in Figure 1.

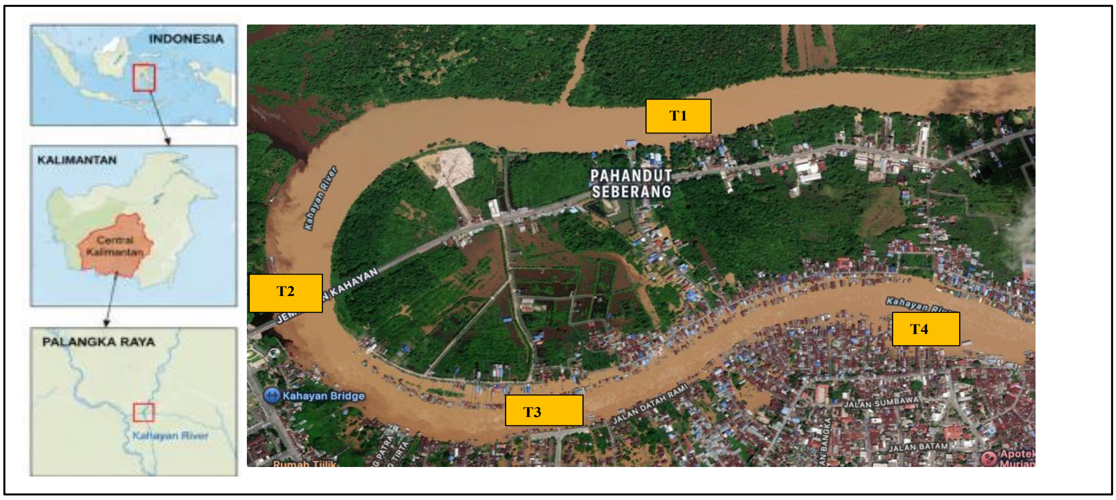

Figure 1. Locations of the four sampling stations along the Kahayan River, Central Kalimantan, Indonesia (T1: 2.19687° S, 113.93196° E; T2: 2.20299° S, 113.92061° E; T3: 2.20565° S, 113.92869° E; T4: 2.20370° S, 113.94016° E)

3.1. Microplastic Abundance

Microplastic abundance was quantified to evaluate spatial variations among the four sampling stations. The mean abundance of microplastics at each station presented in Table 2.

Table 2. Microplastic abundance at the four sampling stations along the Kahayan River.

Station	Representative Location Description	Mean ± SD (particles/L)	Group*
T1	Upstream, Riverbank settlements, medium density, direct access for domestic wastewater disposal	10.13 ± 1.01	a
T2	Middle, Under-bridge area, dense shrubs/aquatic plants, public area, and a cross-country route	10.33 ± 1.97	ab
T3	Middle-Downstream, Dense settlements, sampling location in the main current with high speed	5.80 ± 0.92	b
T4	Downstream, Dense settlements and active ports, slow currents, potential for sedimentation	7.20 ± 0.20	ab

** Different letters indicate statistically significant differences according to the Games–Howell post hoc test.*

Microplastics were detected at all sampling stations, with mean abundances ranging from 5.80 ± 0.92 to 10.33 ± 1.97 particles L^{-1}. The highest abundance was recorded at Station T2 (10.33 ± 1.97 particles L^{-1}), followed closely by Station T1 (10.13 ± 1.01 particles L^{-1}). In contrast, the lowest abundance was observed at Station T3 (5.80 ± 0.92 particles L^{-1}), while Station T4 exhibited an intermediate abundance of 7.20 ± 0.20 particles L^{-1}. The results of the statistical analyses are summarized in Table 3.

Table 3. Statistical analysis of differences in microplastic abundance among sampling stations.

Statistical analysis	Result
Shapiro–Wilk normality test	Data were normally distributed ($p > 0.05$)
Levene's test	Variances were not homogeneous ($p = 0.045$)
Welch's ANOVA	Significant differences among sampling stations (Welch = 9.577; $p = 0.035$)
Games–Howell post hoc test	Significant difference observed only between Stations T1 and T3 ($p = 0.018$)

The Shapiro–Wilk test confirmed that the abundance data were normally distributed, whereas Levene's test indicated heterogeneity of variances among sampling stations. Consequently, Welch's ANOVA was applied and revealed a statistically significant difference in microplastic abundance among stations ($p = 0.035$). Subsequent pairwise comparisons using the Games–Howell post hoc test demonstrated that a significant difference occurred only between Stations T1 and T3 ($p = 0.018$), whereas no significant differences were detected among the remaining station pairs.

The spatial variation in mean microplastic abundance among sampling stations is illustrated in Figure 2.

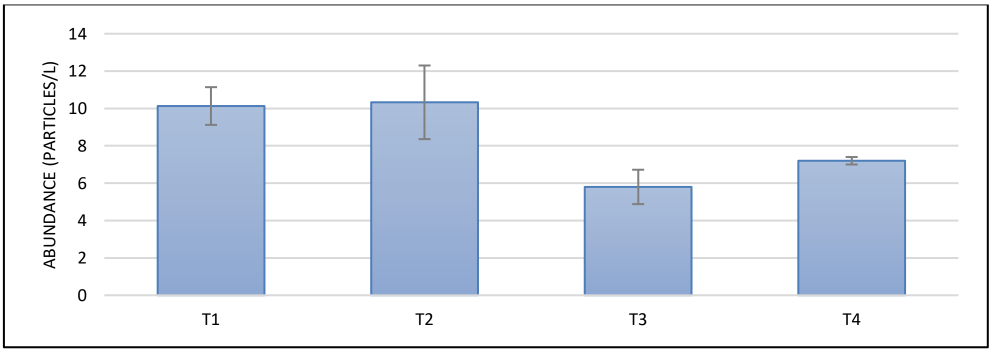

Figure 2. Mean microplastic abundance (particles L^{-1}) at the four sampling stations

3.2. Characteristics of Microplastics

The microplastics identified in the surface water of the Kahayan River were characterized according to their morphology, particle size, and color. The distribution of these characteristics is summarized in Table 4, while their graphical representation is shown in Figure 3.

Table 4. Characteristics of microplastics

Characteristics	N	%
Morphology		
Fiber	358	71,31
Fragment	144	28,69
Total	502	100,00
Size (mm)		
0,101–0,500	158	31,47
0,501–1,000	180	35,86
1,001–5,000	164	32,67
Total	502	100,00
Color		
Transparent	256	51,00
Brown	110	21,91
Black	109	21,71
Blue	17	3,39
Red	9	1,79
Green	1	0,20
Total	502	100,00

The characteristics of microplastics identified in the surface water of the Kahayan River, including their morphology, size, and color, are summarized in Table 4. Morphologically, fibers were the predominant microplastic type, accounting for 358 particles (71.31%), whereas fragments comprised 144 particles (28.69%). Based on particle size, the 0.501–1.000 mm size class was the most abundant, representing 35.86% of the total particles, followed by the 1.001–5.000 mm (32.67%) and 0.101–0.500 mm (31.47%) size classes. Regarding color, transparent microplastics were the dominant category (51.00%), followed by brown (21.91%) and black particles (21.71%). In contrast, blue (3.39%), red (1.79%), and green (0.20%) microplastics were detected at considerably lower proportions.

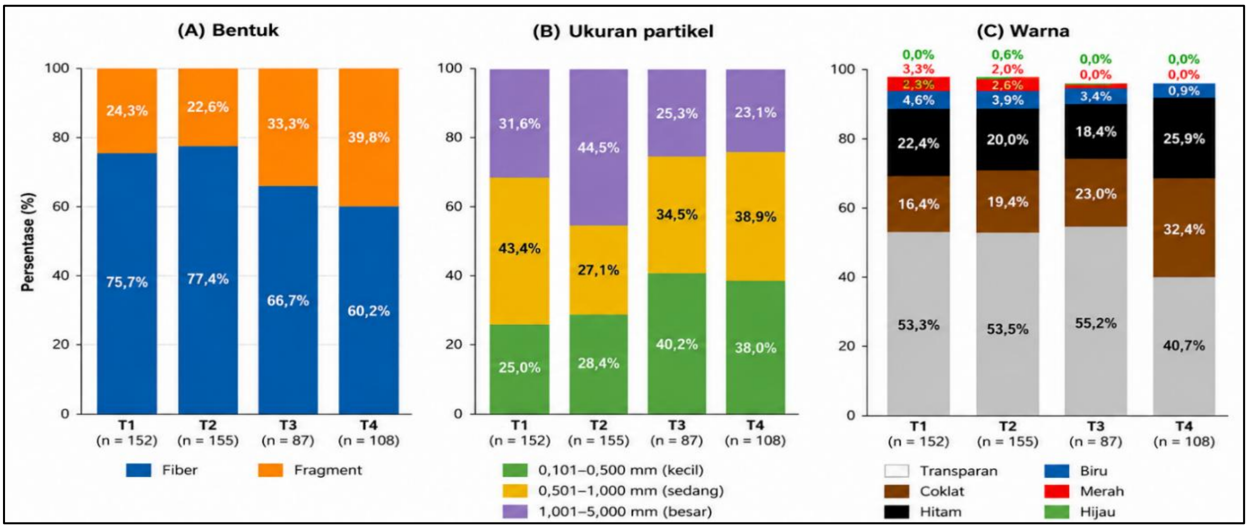

Figure 3. Spatial distribution of microplastic characteristics at the four sampling stations in the Kahayan River according to (A) morphology, (B) particle size, and (C) color.

The distribution of microplastic characteristics at each sampling station based on morphology, particle size, and color is presented in Figure 3. Overall, microplastic characteristics exhibited relatively consistent patterns across the four sampling stations, although slight variations in the proportions of each category were observed.

Based on morphology (Figure 3A), fibers were the predominant microplastic type at all sampling stations, accounting for 60.2–77.4% of the total particles, whereas fragments represented 22.6–39.8%. The highest proportion of fibers was recorded at Station T2 (77.4%), while the highest proportion of fragments was observed at Station T4 (39.8%).

The particle size distribution (Figure 3B) varied among sampling stations. The 0.501–1.000 mm size class predominated at Stations T1 (43.4%) and T4 (38.9%), whereas Station T2 was dominated by particles in the 1.001–5.000 mm size class (44.5%). In contrast, the highest proportion of particles at Station T3 belonged to the 0.101–0.500 mm size class (40.2%).

Regarding particle color (Figure 3C), transparent microplastics were the dominant color category across all sampling stations, accounting for 40.7–55.2% of total particles. The highest proportion of transparent particles was observed at Station T3 (55.2%), whereas the lowest occurred at Station T4 (40.7%). Conversely, Station T4 exhibited relatively higher proportions of brown (32.4%) and black (25.9%) microplastics than the other sampling stations. Blue, red, and green microplastics were detected only in relatively low proportions across all sampling stations.

4. Discussion

4.1. Microplastic Abundance

Microplastics were detected at all sampling stations along the Kahayan River, with mean abundances ranging from 5.80 ± 0.92 to 10.33 ± 1.97 particles L^{-1}. Welch's ANOVA revealed significant differences in microplastic abundance among sampling stations (p = 0.035). However, pairwise comparisons using the Games–Howell post hoc test indicated that a statistically significant difference occurred only between Stations T1 and T3 (p = 0.018), whereas no significant differences were observed among the remaining station pairs. These findings suggest that the spatial distribution of microplastics in the Kahayan River is influenced by site-specific environmental conditions rather than by a uniform pattern along the river continuum.

The spatial distribution of microplastics did not exhibit a simple upstream-to-downstream trend. Instead, microplastic abundance fluctuated among sampling stations, indicating that local environmental characteristics govern transport, retention, and accumulation processes. Consequently, longitudinal position alone cannot adequately explain the observed variation in microplastic abundance.

The present findings are consistent with those reported by Zakiah et al. (2024), who documented microplastics throughout the Kahayan River and demonstrated that their abundance varied with land use and anthropogenic activities along the river. Their study showed that urbanized areas characterized by residential settlements, commercial activities, transportation, and tourism generally exhibited higher microplastic abundances than locations with lower human disturbance. A similar pattern was observed in the present study, where Stations T1 and T2, located within areas of relatively intensive human activity, exhibited higher microplastic abundances than Station T3.

Despite these similarities, the present study provides additional insights beyond those of Zakiah et al. (2024). Whereas the previous study primarily described the distribution of microplastics among different environmental compartments, including surface water, sediment, and fish, across the upstream–midstream–downstream sections of the Kahayan River, the present study focused on four urban sampling stations with contrasting environmental characteristics. Furthermore, Welch's ANOVA followed by the Games–Howell post hoc test enabled a quantitative evaluation of spatial differences in microplastic abundance. This approach provides a more detailed understanding of small-scale spatial variability and complements previous investigations of microplastic contamination in the Kahayan River.

Station T1 exhibited a relatively high microplastic abundance (10.13 particles L^{-1}). Field observations indicated that this station is located adjacent to residential areas, where domestic activities may contribute plastic waste to the river. Although the present study did not directly quantify pollution sources or wastewater discharge, domestic wastewater has been widely recognized as one of the major pathways through which microplastics enter freshwater ecosystems, transporting synthetic textile fibers, plastic fragments, and particles originating from household products (Rentería et al., 2023; Zhi et al., 2023). Therefore, the relatively high abundance observed at Station T1 is likely associated with domestic waste inputs from the surrounding residential area.

The highest microplastic abundance was recorded at Station T2 (10.33 particles L^{-1}). In addition to surrounding anthropogenic activities, this station was characterized by relatively dense riparian and aquatic vegetation. Riparian vegetation can reduce water velocity, enhance the retention of suspended particles, and promote microplastic accumulation through mechanical trapping and biofilm formation on plant surfaces (Tan et al., 2023; Wu et al., 2025). Consequently, microplastics transported from upstream or generated locally may have been retained more efficiently at this station. The elevated abundance at Station T2 therefore likely reflects the combined effects of continuous anthropogenic inputs and favorable hydrodynamic conditions for particle retention.

In contrast, Station T3 exhibited the lowest microplastic abundance (5.80 particles L^{-1}). This station is located within the main river channel, where relatively high flow velocity may facilitate downstream transport of suspended particles and reduce their residence time within the sampling area. Previous studies have demonstrated that river flow velocity strongly influences the spatial distribution of microplastics, particularly for low-density and small particles that remain suspended under high-flow conditions (Boateng et al., 2024a; Dahms et al., 2022). Therefore, the relatively low abundance observed at Station T3 should not necessarily be interpreted as indicating lower pollution levels but rather as reflecting the predominance of particle transport over local retention.

Microplastic abundance increased again at Station T4 (7.20 particles L^{-1}). This station is located near an active harbor and river transportation route, where hydrodynamic conditions differ from those at the other sampling stations. Under relatively calm flow conditions, microplastics may settle and accumulate within bottom sediments, whereas vessel traffic can resuspend sediments, returning previously deposited particles to the water column (Drummond et al., 2022; Ma et al., 2023). These processes may explain the intermediate abundance of microplastics observed at Station T4, despite its lower concentration compared with Stations T1 and T2.

Although the spatial pattern observed in the present study is generally consistent with findings from other rivers in Indonesia and tropical regions, direct comparisons of microplastic abundance among studies should be interpreted with caution. Differences strongly influence reported abundances across sampling methodologies, plankton net mesh sizes, sampling seasons, analytical procedures, and the hydrological characteristics of individual river systems.

Overall, the findings demonstrate that the spatial distribution of microplastics in the Kahayan River results from the interaction of multiple environmental factors rather than from longitudinal position alone. Although the present study did not directly identify pollution sources, the observed spatial patterns provide valuable baseline information for identifying potential zones of microplastic accumulation. Such information may support future river monitoring programs and contribute to the development of location-specific strategies for plastic waste management and freshwater pollution mitigation in the Kahayan River.

4.2 Morphological Characteristics of Microplastics

Microplastics were observed across all sampling stations despite minor variations in their relative proportions. In contrast, Station T4 exhibited a comparatively higher proportion of fragments than the other stations. These findings indicate that the overall morphological composition of microplastics was relatively uniform throughout the study area while still reflecting local environmental conditions and anthropogenic influences.

The predominance of fibers is likely associated with the continuous input of synthetic fibers from domestic and urban activities, including laundering of synthetic textiles, degradation of plastic ropes and fishing nets, and the discharge of household wastewater. Although the present study did not directly identify pollution sources or determine polymer composition, fiber-shaped microplastics are widely recognized as the dominant form in freshwater ecosystems influenced by residential and urban activities. The predominance of fibers is likely associated with the continuous input of synthetic fibers from domestic and urban activities, including laundering of synthetic textiles, degradation of plastic ropes and fishing nets, and household wastewater discharge. Although the present study did not directly identify pollution sources or determine polymer composition, fiber-shaped microplastics are widely recognized as the dominant form in freshwater ecosystems influenced by residential and urban activities (Anand & Sheel, 2025; Vercauteren et al., 2022). Consequently, the high proportion of fibers observed in the Kahayan River most likely reflects the cumulative contribution of multiple anthropogenic sources distributed throughout the watershed.

These findings are consistent with previous studies conducted in Indonesian rivers, including the Citarum and Brantas Rivers (Adrian & Roosmini, 2024; Alam et al., 2023; Ekawati et al., 2024; Rofiq & Sari, 2022), as well as investigations from other Southeast Asian River systems, all of which reported fibers as the dominant microplastic morphology. This predominance is generally attributed to the relatively low density and elongated shape of synthetic fibers, which facilitate suspension and downstream transport within the water column. Compared with larger and more compact fragments, fibers are also less likely to be retained by natural filtration processes and therefore can remain suspended over longer distances.

Although fibers predominated at all sampling stations, the relatively higher proportion of fragments observed at Station T4 suggests spatial variability in the sources and environmental fate of microplastics. Fragments are generally produced by the weathering and fragmentation of larger plastic debris, including single-use packaging, plastic bags, and rigid plastics, which are exposed to ultraviolet radiation, temperature fluctuations, and mechanical abrasion. Because the present study did not evaluate particle age or degradation processes, the higher abundance of fragments at Station T4 should be interpreted with caution as an indication of differences in local pollution sources or hydrodynamic conditions rather than as direct evidence of enhanced fragmentation.

From an ecological perspective, the predominance of fibers has important environmental implications. Owing to their thread-like morphology, fibers are readily ingested by a wide range of aquatic organisms because they resemble natural food items or organic detritus. Moreover, their relatively high surface-area-tovolume ratio enhances their capacity to adsorb heavy metals and persistent organic pollutants, thereby increasing the potential for contaminant transfer through aquatic food webs (Bellasi et al., 2020; Schernewski et al., 2020). Although biological effects were not evaluated in the present study, the predominance of fibers highlights the importance of controlling domestic sources of microplastic pollution as part of freshwater management strategies in the Kahayan River.

4.3. Particle Size Distribution of Microplastics

The particle size distribution revealed that microplastics measuring 0.501–1.000 mm constituted the largest size class (35.86%), followed by particles measuring 1.001–5.000 mm (32.67%) and 0.101–0.500 mm (31.47%). Although the differences among size classes were relatively small, the results indicate that medium-sized microplastics predominated in the surface water of the Kahayan River. Spatially, the dominant size class varied among sampling stations. Stations T1 and T4 were characterized primarily by particles measuring 0.501–1.000 mm, whereas Station T2 contained a higher proportion of 1.001–5.000 mm particles. In contrast, the smallest size class (0.101–0.500 mm) was most abundant at Station T3.

The observed spatial variation in particle size is likely associated with differences in hydrodynamic transport and fragmentation processes within the river. Smaller particles generally possess lower settling velocities and therefore remain suspended in the water column for longer periods, whereas larger particles are more susceptible to sedimentation under low-flow conditions. Although hydraulic parameters such as flow velocity and discharge were not directly measured in this study, the observed differences in particle size distribution suggest that local hydrodynamic conditions may play an important role in controlling the transport and retention of microplastics among sampling stations.

These findings agree with previous studies demonstrating that particle size is a major factor governing microplastic transport in freshwater environments (Boateng et al., 2024b; Dahms et al., 2022). Smaller particles generally exhibit longer residence times because they are transported more efficiently by river currents, whereas larger particles are more likely to settle when flow velocity decreases. Furthermore, Zhang et al. (2024) reported that temporal and spatial variations in hydrological conditions can redistribute microplastics through transport, sedimentation, and resuspension, thereby altering the local particle-size composition.

Compared with the study conducted by Zakiah et al. (2024) in the Kahayan River, the present results show a similar overall pattern, with small- to medium-sized microplastics predominated over larger particles. However, the present study provides a more detailed assessment of spatial variability by comparing multiple sampling stations with different environmental settings and levels of anthropogenic activity. This finer spatial resolution improves understanding of how local environmental conditions influence the distribution of microplastic particle sizes within the river.

The predominance of small- and medium-sized microplastics has important ecological implications because particles within these size ranges are readily ingested by a broad spectrum of aquatic organisms, from zooplankton to fish. In addition, their relatively high specific surface area enhances their capacity to adsorb heavy metals and persistent organic pollutants, thereby increasing the likelihood of contaminant transfer through aquatic food webs (Bellasi et al., 2020; Yilmaz et al., 2024). These findings emphasize the need for continued monitoring of microplastic exposure in freshwater biota and the potential ecological risks associated with trophic transfer in the Kahayan River ecosystem.

4.4. Color Distribution of Microplastics

The color distribution of microplastics in the Kahayan River was dominated by transparent particles (51.00%), followed by brown (21.91%) and black (21.71%) particles, whereas blue (3.39%), red (1.79%), and green (0.20%) particles occurred at considerably lower proportions. Spatially, transparent microplastics predominated at all sampling stations, although their relative abundance varied among locations. In contrast, Station T4 exhibited comparatively higher proportions of brown and black microplastics than the other sampling stations.

The predominance of transparent microplastics suggests that this color category represents the most common characteristic of microplastic particles in the surface water of the Kahayan River. Because polymer composition and particle weathering were not examined in the present study, particle color cannot be directly interpreted as an indicator of polymer type or degradation stage. Nevertheless, previous studies have demonstrated that prolonged exposure to ultraviolet radiation, oxidative processes, and mechanical abrasion can progressively alter the color of plastic materials, resulting in faded or transparent particles during environmental weathering (Alirezazadeh et al., 2022; Anand & Sheel, 2025). Therefore, the predominance of transparent particles observed in this study is likely associated with a combination of the original characteristics of plastic materials entering the river and subsequent weathering processes occurring within the aquatic environment.

The relatively higher proportions of brown and black microplastics at Station T4 indicate spatial heterogeneity in microplastic characteristics among sampling locations. This variation may reflect differences in the types of plastic materials entering the river as well as local hydrodynamic processes, including transport, deposition, and resuspension. However, because the polymer composition and specific pollution sources were not determined, these explanations should be regarded as plausible hypotheses that require confirmation through future chemical characterization of microplastic particles.

The present findings are consistent with those reported by Zakiah et al. (2024), who also identified transparent particles as the dominant color category in different environmental matrices of the Kahayan River. Similar observations have been reported in other Indonesian rivers and tropical freshwater ecosystems, where transparent microplastics generally predominate over other color categories. The consistency of these findings suggests that the color characteristics of microplastics in the Kahayan River are broadly comparable to those reported for other river systems subjected to intensive anthropogenic pressures.

From an ecological perspective, particle color may influence the likelihood of microplastic ingestion by aquatic organisms. Several studies have suggested that transparent and dark-colored particles visually resemble plankton, detritus, or other natural food items, thereby increasing the probability of accidental ingestion by fish and other aquatic organisms (Bellasi et al., 2020; Schernewski et al., 2020). Although biological uptake was beyond the scope of the present study, the predominance of transparent microplastics across all sampling stations highlights the need for further investigations into the ecological consequences of microplastic ingestion and the potential transfer of these particles through freshwater food webs.

4.5. Implications for Microplastic Pollution Management and Mitigation

The present study demonstrated that microplastics were detected at all sampling stations along the Kahayan River, with spatial variations in both abundance and physical characteristics. These findings indicate that microplastic contamination has become widespread throughout river sections influenced by diverse anthropogenic activities. Although the present study did not directly assess human health risks or compare the observed concentrations with regulatory standards, the detection of microplastics at all sampling locations highlights the need for preventive management strategies targeting pollution sources. At present, no regulatory threshold for microplastics in surface water has been established in Indonesia, making baseline monitoring studies such as this one essential for supporting future environmental policies and water quality assessments.

Based on the observed spatial distribution, mitigation efforts should prioritize reducing plastic inputs from residential areas and other human activities along the Kahayan River. Potential management measures include improving household solid waste management, reducing the consumption of single-use plastics, providing adequate waste collection facilities in recreational areas and river ports, and enhancing public awareness regarding the environmental consequences of disposing of plastic waste into river systems. Preventive measures that address pollution at its source are generally considered more effective than downstream clean-up activities because they reduce the continuous input of plastic debris into aquatic environments.

The results also indicate that local environmental characteristics influence the distribution of microplastics among sampling stations, suggesting that management strategies should be adapted to site-specific conditions. In residential areas, improving domestic waste and wastewater management should be prioritized to minimize plastic inputs into the river. In contrast, areas associated with river transportation and harbor activities require strengthened waste management practices and effective control of plastic waste generated by shipping operations and supporting facilities. Furthermore, maintaining riparian vegetation may contribute to river management by enhancing the retention of suspended particles. However, its effectiveness in retaining microplastics under the environmental conditions of the Kahayan River requires further investigation before it can be incorporated into evidence-based management strategies.

The findings also emphasize the importance of establishing long-term microplastic biomonitoring programs in the Kahayan River. Periodic monitoring across different hydrological seasons, combined with analyses of multiple environmental compartments—including surface water, sediments, and aquatic organisms—would provide a more comprehensive understanding of the sources, transport pathways, and environmental fate of microplastics. Such information would strengthen the scientific basis for river management policies, support the conservation of freshwater ecosystems, and help protect communities that rely on the Kahayan River for domestic, economic, and recreational purposes.

4.6. Study Limitations

Several limitations of this study should be considered when interpreting the findings. First, the investigation focused exclusively on surface water, and therefore does not provide information on microplastic distribution in sediments or aquatic organisms, which are also recognized as important environmental compartments for microplastic accumulation. Consequently, the present results represent only the surface-water component of microplastic contamination in the Kahayan River.

Second, sampling was conducted during a single sampling period, preventing the assessment of seasonal variability in microplastic abundance and characteristics. Temporal fluctuations associated with rainfall, river discharge, and hydrological conditions may substantially influence the transport, retention, and redistribution of microplastics in freshwater ecosystems.

Furthermore, hydrological variables, including flow velocity, river discharge, and sediment characteristics, were not quantitatively measured. As a result, the relationships between microplastic distribution and river hydrodynamics could only be inferred from field observations and supported by findings from previous studies. In addition, polymer composition was not determined using spectroscopic techniques such as Fourier Transform Infrared Spectroscopy (FTIR) or Raman spectroscopy, limiting the identification of specific polymer types and the precise attribution of microplastic sources.

Despite these limitations, this study provides the first comprehensive assessment of the spatial distribution and physical characteristics of microplastics in the surface water of the Kahayan River using a biomonitoring approach across four sampling stations representing different anthropogenic settings. The findings establish an important baseline for future investigations integrating multiple environmental compartments, polymer identification, hydrological measurements, and ecological or human health risk assessments. Such studies will contribute to a more comprehensive understanding of microplastic pollution and support evidence-based management of the Kahayan River.

5. Conclusions

Microplastics were detected at all sampling stations along the Kahayan River, with abundances ranging from 5.80 ± 0.92 to 10.33 ± 1.97 particles L^{-1}. Significant spatial variation in microplastic abundance was observed among sampling stations, although a statistically significant difference was detected only between Stations T1 and T3. The identified microplastics were predominantly fibers (71.31%), followed by particles measuring 0.501–1.000 mm (35.86%) and transparent particles (51.00%). These findings indicate that the spatial distribution of microplastics in the Kahayan River is governed primarily by local environmental conditions and anthropogenic activities rather than by a simple upstream-to-downstream gradient.

This study provides the first detailed assessment of the spatial distribution and physical characteristics of microplastics in the surface water of the urban reaches of the Kahayan River. The findings establish an important baseline for long-term microplastic monitoring and contribute to a better understanding of microplastic contamination in tropical freshwater ecosystems. The results may also support the development of evidence-based management strategies to reduce plastic pollution in the Kahayan River.

Future studies should incorporate multiple environmental compartments, including surface water, sediments, and aquatic biota, together with polymer identification using spectroscopic techniques and quantitative hydrological measurements. Such integrated approaches will provide a more comprehensive understanding of the sources, transport mechanisms, environmental fate, and ecological risks of microplastics in the Kahayan River.

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