

Article

Adapting Sampling Methods to River Characteristics: A Comparative Study of Microplastic Collection in Low-Flow Rivers

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Abstract

Microplastics, plastic particles smaller than 5 mm, are significant pollutants of growing global concern due to their persistence, widespread distribution, and potential ecological and human health risk. Numerous studies have proposed different methods for sampling microplastics in river sediments and water. However, comparative studies evaluating how different sampling methods affect the quantification of microplastic abundance in surface water remain limited. This study focused specifically on surface water, as it represents the primary pathway of microplastic transport, and the yield is most directly influenced by sampling method selection. Therefore, this study aimed to compare the abundance and characteristics of microplastics collected using three sampling methods: plankton nets, buckets, and pumps, which were selected to represent the full spectrum of commonly used riverine surface water collection approaches. Each method collected an equivalent volume of water, 1000 L. Statistical analysis showed no significant differences among the methods in terms of microplastic abundance and characteristics. These results suggest that the selection of a sampling method should be primarily based on river characteristics such as flow velocity, depth, and channel width rather than methodological differences. The findings provide practical guidance for selecting appropriate sampling approaches in low-flow river environments.

Keywords: microplastics; sampling methods; abundance; surface water



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1. Introduction

Microplastics, plastic debris with a size smaller than 5000 µm, have become a major concern due to the consistent growth in plastic production and disposal, after which they accumulate in aquatic environments. Since their commercial development in the 1940s, global plastic production has increased rapidly, surpassing 300 million tons annually by 2014 [1]. Hence, the quantity of plastic that is released into the aquatic environment is difficult to measure, but it is estimated that 11% of the plastic waste generated is between 4 and 23 million metric tons each year globally [2–4].

The discrepancies in microplastic data quality and comparability arise from variations in sampling techniques, analytical methods, and instruments; hence, appropriate equipment is necessary to obtain accurate and representative microplastic data [5,6]. Sampling

is the critical first step in understanding this issue. Surface water microplastic sampling methods can be categorized into three main types: volume-reduced filtration, grab sampling, and pumped sampling [7–9]. Volume-reduced filtration methods, such as plankton nets and manta trawls, are widely used as a standard method for assessing microplastic pollution in aquatic environments and are included in several harmonized protocols for riverine microplastic sampling, as they allow for the collection of large water volumes [10–12]. This method is considered relatively time-efficient, making it advantageous for large-scale or repeated field applications. Buckets or bottles are included in the grab sampling method to collect water and sieve the water in the field [13–15]. They offer simplicity and low contamination risk but are typically limited to smaller volumes and the surface layer. Pump sampling involves either manually pumping the water or using an inline filter with a motor [16], which can collect larger volumes that may be strengthened in rivers with a low abundance of microplastics. The performance of different mesh size sampling methods, such as 100 μm vs. 300 μm plankton nets, and various methods, including manta nets with 333 μm mesh sizes vs. in situ pumps, bulk water vs. plankton nets, manta and grab vs. pump methods, and net and pump vs. sedimentation boxes, have been compared [17–19]. Owing to the complexity of sampling collection, which depends on the sampling location and characteristics (geographic location, width, etc.), sampling conditions (wind, current, etc.), and available instruments, all of which may differ, a unified collection method is difficult to establish [20]. It is well accepted that different sampling methods, or even different sampling volumes, result in different microplastic abundances [21,22].

Nevertheless, collecting microplastics from rivers under low-flow conditions can be particularly challenging. In Japan, the Ministry of the Environment [10] recommends the application of a direct plankton net method for microplastic sampling in rivers. However, in shallow or very low-flow rivers (depth < 30 cm; velocity < 0.1 m s^{−1}), plankton nets often do not reach even half the submergence, so the minimum requirement of “half of the plankton net submerged” [23–25] is not met, making the sampled water layer and filtered volume poorly defined and leading to biased, unrepresentative estimates of the microplastic concentration. Additionally, during rainfall events, when sampling must be conducted from a bridge because of safety restrictions, and the water flow becomes significantly faster, rapid deployment of a plankton net is needed to ensure the comparability of volume collected on sunny days. Owing to the availability of sampling devices and equipment, researchers often face a problem between sampling volume and methodological representativeness.

Although microplastics are known to be present in a variety of environmental matrices, such as sediments and aquatic organisms [22,26,27]. This study specifically focused on surface water matrices for two reasons. First, surface water serves as a major pathway for microplastic transport and downstream distribution in river systems. Second, the performance of the most direct and measurable sampling methods is affected by water column conditions such as flow velocity, depth, and filtered volume, making surface water the most appropriate matrix for direct methodological comparison [19,28]. Comparative studies were predominantly conducted in marine, estuarine, or high-flow riverine environments, where sufficient water depth and flow velocity ensure stable operation of sampling tools [5,18,29]. The performance of these methods under low-flow and shallow-water conditions has received limited attention. Furthermore, no direct field-based comparison of all three methods with sample volume filtered under such restrictive conditions has been conducted, representing a critical gap in current microplastic sampling methodology.

This raises several important questions: Which sampling method is most appropriate under restrictive field conditions? Is one method inherently superior to others? While it is well established that sampling volume can influence the reported abundance of mi-

croplastics, the extent of variation across sampling techniques remains unclear. Can a single method be recommended for use under a wide range of environmental conditions? To date, direct field-based comparisons among the three commonly used methods, especially for surface water, have not been conducted. Therefore, conducting an on-site comparative study of microplastic sampling methods is essential for improving our understanding and enabling more accurate assessments of environmental microplastic pollution. Hence, the goal of this study is to elucidate the differences in the abundance and characteristics of microplastics using three sampling methods: plankton net, bucket, and pump, with a sample volume of 1000 L, in low-flow rivers. These methods were selected because they represent the most commonly applied in riverine microplastic studies and are practically deployable across varying low-flow field conditions. The goal is to recommend an appropriate sampling method that should be selected on the basis of river characteristics for better insight into microplastic data.

2. Materials and Methods

2.1. Sampling Sites

The three sampling methods for microplastics were tested using triplicate surface water samples from three sampling sites, particularly in the flow into Mikawa Bay (as shown in Figure 1), and were conducted on sunny days in September 2024. The weather data for the sampling date are presented in Supplementary Table S1. These sampling sites have been selected to assess the relevance of the sampling method and can be applied to similar low-velocity flows but to different land-cover types, land-cover characteristics, and river catchment areas, as represented in Table 1 (<https://nlftp.mlit.go.jp/ksj/index.html> (accessed on 25 July 2025)). First, the sampling site (34°42′44.0″ N 137°23′46.1″ E) was located in the Umeda River, which is 61% affected by agricultural activities with a mean river depth of 400 mm, a velocity of 0.30 m/s, a river discharge of 0.21 m³/s, and a total river width of 15 m (Supplementary Figure S1).

Table 1. Land cover (%) within the catchment of the sampling site.

Sampling Site (River)	Catchment Area (km ²)	Land Cover (%)			
		Forests and Wastelands	Farmland: Paddy Fields and Fields	Urban and Built-Up	Water
Umeda	61.8	11.2	60.5	26.2	2.1
Yagyu	5.5	14.4	10.6	72.8	2.2
Toyo	643	77.4	14.5	6.1	2.0

The second sampling site (34°46′38.6″ N 137°24′24.6″ E) is the Toyo River, which is 73% dominated by forestland and has a mean depth of 465 mm, a velocity of 0.15 m/s, a river discharge of 1.22 m³/s, and a river width of 33 m (Supplementary Figure S2). Finally, the site (34°45′14.9″ N 137°23′30.3″ E) is the Yagyu River, which is 73% urbanized and has a high population density, with a mean velocity of 0.11 m/s, a river discharge of 0.14 m³/s, a mean depth of 630 mm, and a wetted river width of 7.8 m (Supplementary Figure S3). The antecedent dry day (ADD) before the sampling event was one day for all rivers. All sampling points were selected at the downstream end of each river before it discharges into Mikawa Bay, as this location combines microplastic inputs from the entire catchment. Furthermore, these locations corresponded to established routine monitoring sites that provided adequate access and hydrological conditions for the simultaneous application of all three sampling methods.

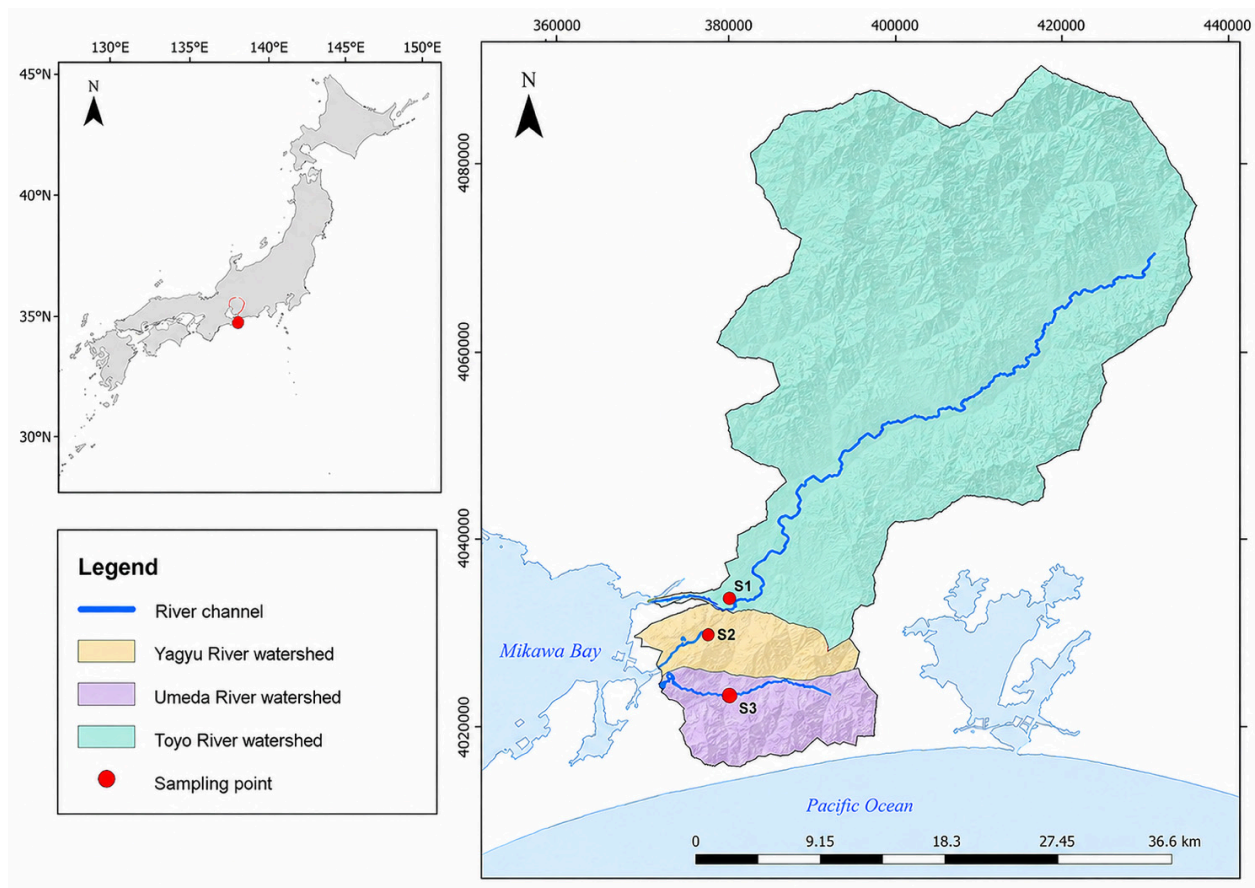


Figure 1. Sampling location and catchment boundaries.

2.2. Sample Collection

Sampling was carried out following the methods described in [30], who established 10 essential criteria for robust field sampling procedures. At every site, candidate microplastics were collected using three different sampling methods: plankton net (PN), bucket (B), and pump (PU). The arrangement of sampling methods, which were conducted at a depth of approximately 20–50 cm from the surface of the water [31], suggested that a minimum volume of 0.5 to 1 L per replicate offers a practical balance between feasibility and data quality across different sampling approaches. However, because the abundance of microplastics is typically reported as particles per cubic meter (particles/m³) in global studies, this study used a sampling volume of 1000 L to ensure reliable quantification. To allow for a more accurate comparison among the sampling methods, samples from each site were replicated three times; samples from each site were taken on the same day and initiated at the same starting time; however, the time required to reach 1000 L varied depending on the river flow conditions at the time of sampling, ranging from 2 to 20 min.

The first method used a fixed plankton net in accordance with the guidelines for riverine microplastics published by the Ministry of Environment Japan (MOEJ) [10]. A cone-shaped plankton net with a cod end was measured in the center of the river channel. The net measured 75 cm in length and 30 cm in diameter, with a 300 µm mesh size. The plankton net trawl duration was approximately 2–3 min at a river flow velocity of approximately 0.1–0.3 m/s. For the second method, 1000 L were collected at the center of the river channel using a 5 L stainless-steel bucket and then filtered through a 300 µm plankton net.

Surface river water was collected by a centrifugal water pump (KP2521MA Water Pump, Maruyama Co., Tokyo, Japan) for the third method. The suction hose has a 50 mm

mesh filter to prevent large debris from entering the pump system. Before sampling, the hose and pump were primed for 10 min and rinsed with surface water. The pump was calibrated three times using a manual timer to ensure accurate volume collection, with the timer adjusted to match the pump's discharge rate, which was up to 115 L/min. The discharged water was filtered through a 300 µm plankton net. At the Umeda and Toyo rivers, pump sampling was conducted approximately 4–6 m away from the riverbank, depending on site conditions. However, in the Yagyu River, due to the narrow channel width, the intake was positioned at the center of the river. The intake suction was submerged to a depth of 5–10 cm below the surface water. Afterward, the plankton net collection was placed vertically and thoroughly rinsed with river water from the outside inward to ensure that all trapped particles were collected on the basis of the procedure described by [32]. All the plankton nets containing candidate microplastics were sealed and brought to the laboratory for further analysis.

2.3. Microplastic Extraction

The extraction of the microplastics in the laboratory was performed according to the methods described in [10], and the plankton nets were subsequently washed with ultrapure water 5 times to ensure that no microplastic candidates remained in the glass beaker and then dried in a 55 °C oven until completely dry. The samples were then digested with 200 mL of 30% H₂O₂ and stored at 55 °C for 5–7 days until the organic matter was completely digested. The digested solution was then filtered through a plankton net and rinsed 5 times to ensure that no candidate microplastics remained by using a circulating aspirator (Shibata Scientific WJ-20, Saitama, Japan). Afterward, the samples were density separated using a saturated sodium iodide (NaI) 5.3 M solution with a density of 1.5 g/cm³. Floating particles (<1.5 g/cm³) were then vacuum filtered and rinsed with ultrapure water, and the higher-density fraction (>1.5 g/cm³) was also filtered through a 300 µm net and manually inspected for candidate MPs to maximize recovery. To ensure no candidate microplastics remained, the density separation was repeated 5 times. The candidate microplastics were stored in glass petri dishes and air-dried at room temperature for further analysis.

2.4. Observation and Identification of Microplastics

Potential microplastics were first examined under a stereomicroscope (Moticam S3, Shimadzu Rika Co., Ltd., Tokyo, Japan) to assess their size, color, and shape. Fourier transform infrared (FTIR) spectroscopy (Cary 630 FTIR spectrometer, Agilent Technologies, Santa Clara, CA, USA) with a range of 650–4000 cm^{−1}, a resolution of 8 cm^{−1}, and 32 background scans was used to determine the chemical composition. The spectra of the candidate microplastics were compared to a reference library consisting of twenty-one standard polymer spectra and nine commercial plastic spectra, including those of polypropylene (PP), polyethylene (PE), polystyrene (PS), polyamide (PA), polyurethane (PU), polyethylene terephthalate (PET), and polyvinyl chloride (PVC). Polymer types with a spectrum match rate of more than 70% are considered acceptable for identification as microplastics [10].

2.5. Contamination Control and Quality Assurance

To ensure quality control in the microplastic analysis, this study adopted seven key contamination control measures as recommended by [26,31]. All sampling equipment and laboratory glassware were thoroughly cleaned with ultrapure water before use. After sampling, all instruments were rinsed with ultrapure water and anhydrous ethanol, then wrapped in aluminum foil to minimize the risk of atmospheric contamination. Throughout the study, researchers wore nitrile gloves, cotton clothing, and lab coats and avoided

plastic products whenever possible. To further reduce airborne microplastic contamination, FTIR analysis was performed under controlled indoor conditions, with the temperature maintained below 26 °C and relative humidity below 50%. An air purifier (DCE-120, Iris Ohyama, Miyagi, Japan) was operated continuously, and personnel movement in the laboratory was kept to a minimum. Potential contamination was controlled using several types of blanks during sorting and processing. During sampling, environmental samples were collected in stainless steel buckets and analyzed as environmental blanks to assess background contamination. Air contamination was evaluated by placing three open glass Petri dishes (ϕ 91 mm) on a laboratory bench and filling them with purified water for 24 h. During sample handling, triplicate 2 L purified water samples used in the laboratory procedures were processed to check for water contamination. All blanks were subjected to the same extraction procedure as previously mentioned, and no microplastics were detected, indicating that contamination from the environment, laboratory air, and laboratory water is negligible. Additionally, the recovery rate of this laboratory extraction method is 98%.

2.6. Data Analysis

The abundance of microplastics in the river surface water was expressed as particles/m³ by dividing the number of detected microplastics by the water volume [33]. Statistical analyses were performed using Microsoft Excel 2019, Origin 2025 (OriginLab Corporation, Northampton, MA, USA), and SPSS 22.0 (IBM, Armonk, NY, USA) software. The Shapiro–Wilk test revealed that the microplastic distributions for each sampling method were not normally distributed ($p < 0.05$). Therefore, nonparametric tests, including the Kruskal–Wallis test, were used to analyze the differences in microplastic abundance among the different sampling sites and methods ($p < 0.05$). When the Kruskal–Wallis test indicated differences among groups, Dunn’s post hoc test with Bonferroni correction was applied to identify which pairs differed significantly. Furthermore, to determine the consistency of the ranking of microplastic abundance across replications, Kendall’s tau (τ) correlation coefficient was employed. Data visualization was performed using ArcGIS Pro 2025 (ESRI, Redlands, CA, USA).

2.7. Assessment of Microplastic Data Quality

This study was evaluated using the quality assessment framework proposed [30] which includes ten criteria divided into two subsets: (1) sampling site details (criteria 1–5), assessing site characteristics and study context; and (2) sampling methods and strategy (criteria 6–10), evaluating the appropriateness of the sampling approach and equipment used. Each criterion was scored from 0 to 2 based on the level of detail and adherence to quality standards. A score of 2 indicates full compliance with data quality objectives, 1 indicates partial compliance, and 0 indicates noncompliance. The total quality score, with a maximum of 20, reflects the reliability and completeness of the field sampling procedures (Supplementary Table S1).

3. Results and Discussion

3.1. Assessment Results of Microplastic Data Quality

This study followed the recommended quality criteria, which include sampling site details and a sampling method strategy [30]. This framework was designed to improve surface water sampling procedures and ensure the collection of high-quality data in terms of accuracy, representativeness, comparability, and completeness. Based on the established quality criteria, the present study achieved a total score of 19/20. This high score reflects careful consideration of the complexity of fluvial processes that influence microplastic distribution, while still meeting key standards for representativeness, comparability, and

completeness (Supplementary Table S2). The study received 1 out of 2 points for temporal resolution, as sampling was conducted at a single time point. However, this approach was justified based on relevant flow conditions and site accessibility at the time of sampling.

Notably, the overall scores reported in studies of river surface waters ranged from 4 to 15, with a mean of 10.5 [30]. Comparisons of microplastic sampling methods must consider (1) sample volume to ensure a representative number of particles per sample and (2) replication to help address the spatial variability of plastic pollution. This study also applies this principle, yet replication was conducted three times within the same timeframe.

3.2. Comparison of the Abundance of Microplastics

Plankton nets, buckets, and pumps were used to compare the abundance of microplastics collected by each method. Figure 2 represents the microplastic abundance across three river sites using three sampling methods. At the Umeda River, the bucket method shows the highest average microplastic abundance at approximately 3.7 particles/m³, followed by the pump and plankton net methods, which yield slightly lower values of approximately 3.0 and 2.8 particles/m³, respectively. In contrast, the Toyo River displays low microplastic abundance across all methods, with values less than 2 particles/m³. Among them, the plankton net records slightly higher levels, while the bucket method did not detect any microplastics. At the Yagyu River, microplastic abundance is moderate across all methods, generally ranging between 1.5 and 2.0 particles/m³. The plankton net and pump methods show slightly higher averages than the bucket method, although the differences are not substantial. Since the microplastic abundance collected by the bucket and pump methods was not normally distributed, the Kruskal–Wallis test was used for testing the microplastic abundance difference between sampling methods; there is no significant difference in variance across methods ($p = 0.534 > 0.05$).

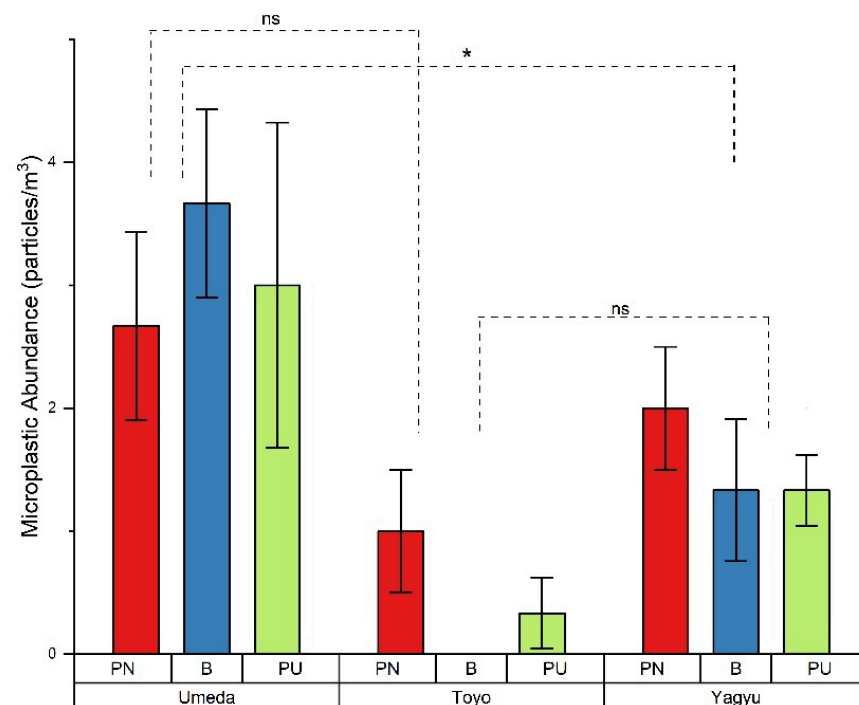


Figure 2. Microplastic abundance in each sampling area determined by the plankton net (PN), bucket (B), and pump (PU) sampling methods. Significance markers between sites are based on Dunn's post hoc test: *: significant, ns: not significant.

The sampling sites included agricultural and urban rivers, resulting in significant variation in their abundance. Specifically, the agricultural river, Umeda River, is three times

more abundant than the urban rivers, Toyo River and Yagyu River. A statistically significant difference among the three rivers was confirmed by the Kruskal–Wallis test ($p = 0.0017$). Dunn's post hoc test with Bonferroni correction indicated that the Umeda River differed significantly from the Toyogawa River ($p = 0.027$), while no significant differences were observed between the Umeda and Yagyu Rivers ($p = 0.470$) or between the Toyogawa and Yagyu Rivers ($p = 0.699$). Agricultural activity may involve less proper waste management, and compared with urban and forested catchment areas, agricultural systems can transport microplastics from agricultural fields via plastic materials, such as mulch sheets and coated fertilizer. In contrast, urban rivers often exhibit a relatively high microplastic abundance, which is positively correlated with population density and the size of industrial, residential, and traffic areas [34,35].

The effectiveness of each sampling method at the study sites is influenced by the characteristics of each sampling location. In the Umeda River, which has the fastest flow velocity (0.30 m/s) and has the entire cross-section of the river filled with water, all the sampling methods were likely effective. However, the bucket method may have increased the yield through a multidirectional approach, which likely increased the abundance of the captured microplastics. In the Toyo River Basin, which is characterized by forestland and wasteland, the plankton net likely captured a higher yield of microplastics but the lowest abundance compared with the others because of the catchment area. Similarly, in the Yagyu River, which has the lowest flow and is surrounded by a densely populated area, the plankton net method likely captured the most abundant microplastics compared with the other methods. In addition to the sampling method, the lateral position during sample collection can influence microplastic abundance.

In this study, plankton net and bucket samples were collected from the middle of the stream, while pump samples were collected closer to the riverbank, except at the Yagyu River, which has a channel width of 3 m, where all the samples were taken from the center of the stream. The spatial distribution of microplastic fluxes and particle properties in a river cross-section demonstrated that high-flow conditions affect lateral and vertical microplastic fluxes, river morphology affects microplastic fluxes, and storm events affect the variety of microplastics across a river section [36]. Moreover, the river cross-sections revealed that the microplastic concentrations and loads were greater on the cut bank than on the slip-off slope, primarily because of variations in flow velocity, greater discharge, and greater abundance of microplastics [37].

Kendall's tau correlation analysis was performed to assess the consistency of the replications for each sampling method and river (as shown in Figure 3). The results showed varying levels of consistency across methods and locations. The pump method demonstrated the greatest consistency, with strong positive correlations in Toyo and Yagyu ($\tau = 0.82$), indicating stable and consistent results across replications. In contrast, the plankton net method showed perfect negative correlations ($\tau = -1.00$) in Umeda and Yagyu, suggesting highly inconsistent or even reversed replication patterns. The bucket method showed weak or no correlation across all the rivers, with τ values ranging from 0.00 to 0.33, and no variation was observed in Toyo because of all the zero results. Based on the results of Kendall's Tau, the pump method appears more robust and consistent for microplastic sampling in rivers, especially where flow conditions are stable.

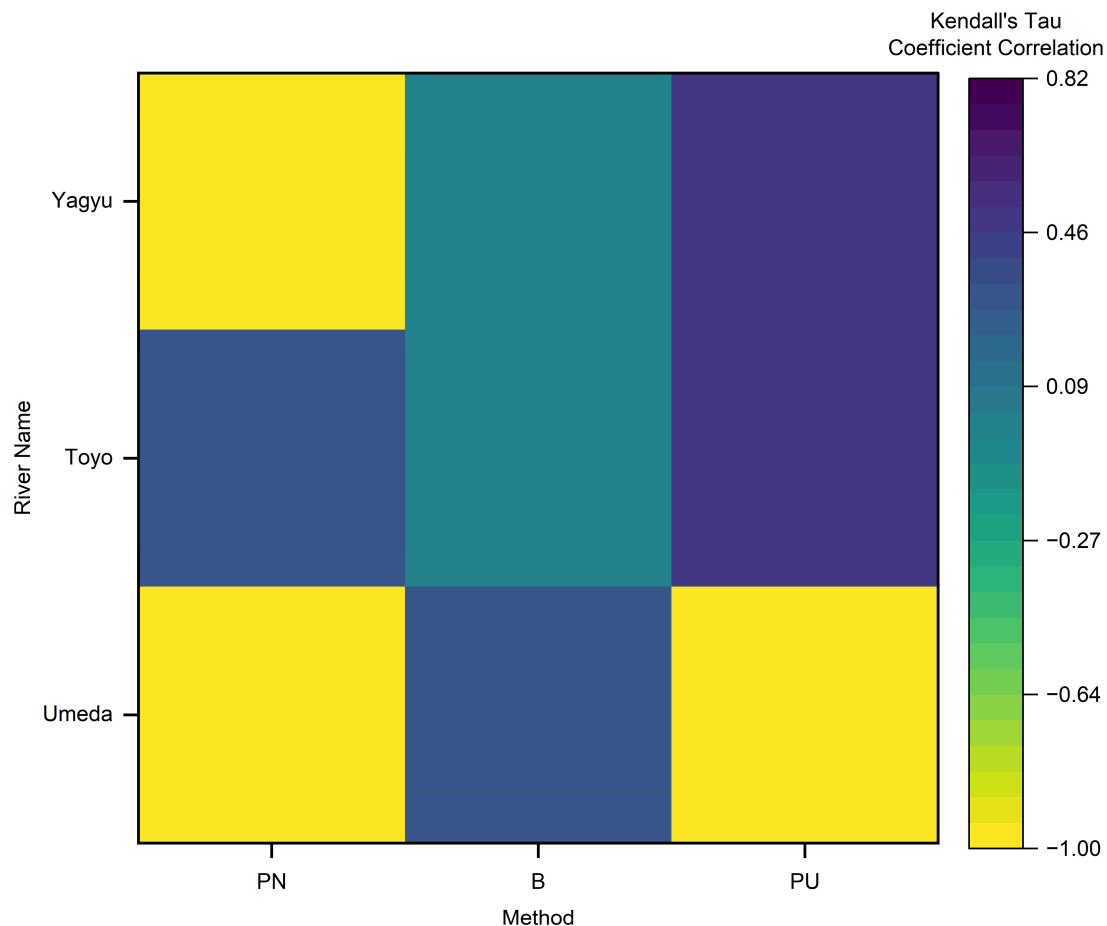


Figure 3. Kendall's tau coefficient correlation in the first, second, and third replications based on the sampling method at each sampling site.

3.3. Sampling Method Comparison

Surface water sampling procedures are generally divided into two main categories: bulk sampling and volume-reduced sampling [7]. Bulk sampling involves direct collection into a container, such as a stainless-steel bucket, glass bottle, or plastic container, without any filtration at the time of collection. On the other hand, volume-reduced sampling uses filtration methods, such as plankton nets or manta trawls, to isolate microplastics directly from the water column [38]. Given that most microplastics are buoyant, more than 140 studies have sampled surface water by using nets, which enabled large-scale sampling [39]. Flow meters are often attached to the nets, allowing researchers to measure the water volume and observe clogging during sampling [40].

Each sampling method has its advantages and disadvantages. As crucial as having a standardized water collection protocol is that the preferred method must be tailored to the research objective, available resources, and prevailing conditions in the study area. The key factor in selecting the bucket method is the sampled volume and sampling depth; if the volume is <500 mL, it provides only a brief overview of a specific location and time, limiting representativeness and increasing uncertainty [39]. Pumping, a type of bulk sampling, enables sampling of larger volumes of water [41]. However, the pump has a relatively high risk of contamination because of the plastic components of pumps, e.g., Teflon, and the mechanical pressure from pumps may also break down microplastics into smaller fragments, potentially altering the size distribution data and generating inaccurate results [42,43].

From the perspective of microplastic abundance and characteristics categorized by color, shape, size, and polymer composition, statistical methods do not significantly in-

fluence their diversity. A crucial aspect of selecting an appropriate method for low-flow study areas is summarized in Table 2, which evaluates various methods on the basis of deployment feasibility, sampling efficiency, contamination risk, and budget constraints. The information presented in this table was compiled and adapted from [44,45] and modified based on the field conditions and findings from the present study. The plankton net method provides a balance between efficiency and cost-effectiveness, making it a widely used option. In particular, the pump enables more capture of smaller microplastic particles and processes large water volumes. Over the past decades, studies on microplastics have suggested that the net and pump methods capture different size ranges of microplastics, and the two approaches are considered complementary instead of replacing one another [39]. On the other hand, bucket methods frequently capture fiber-shaped microplastics, which are predominant in surface water and are often missed in nets and pump methods because of the large mesh and high-speed filtration [46].

Table 2. Comparison of the sampling methods in terms of deployment, sampling efficiency, care for contamination, and cost.

Methods	Deployment	Sampling Efficiency	Care for Contamination	Cost
Direct plankton net	One sufficient person Operable in many different water bodies (marine, estuarine, river)	Net towing is influenced by weather and hydrodynamic conditions Accurate Measurement Easy and rapid replicate sampling	Possibly no cross-contamination	Relatively low cost due to one person handling it
Centrifugal Pump	Requires more equipment and a power source; can be operated by one or two people Operable in many different water bodies (marine, estuarine, river)	Easy and rapid replicate sampling Effective for capturing smaller particles Suitable for a large water volume of sampling It may be challenging to carry out between different sampling points	Equipped with a suction filter to prevent the intake of large debris yet possible contamination from the pipe of the pump or tubing; requires thorough cleaning For a shallow river a significant amount of sediment is likely to be entrained Have	Moderate to high cost for fuel consumption and hose
Bucket stainless steel	Requires at least two people for handling the plankton net and bucket Operable in many different water bodies (marine, estuarine, river)	Limited to surface water Easy to collect, yet complex to replicate with a large volume and time-consuming	Lower likelihood of cross-contamination during sampling due to minimal sampling equipment used	Low to moderate cost due to the need for at least two people

In this study area, the sampling points for all three methods are within a water level range of 600–800 mm, making all the methods feasible. However, when the water depth is less than 300 mm, the direct plankton net method results in only half of the net being submerged, making the sampling slightly unrepresentative. Moreover, in accordance with the MP sampling guidelines issued by MOEJ, the mouth of the net must be fully submerged to ensure proper sampling [10]. Moreover, when the pump method is employed, there is a risk of sediment being introduced into the microplastic data. This raises the question of whether the detected microplastics originate from sediment or surface water.

Several studies have compared different microplastic sampling methods [18,47,48]. Moreover, the abundance of microplastics is influenced primarily by two key factors: the

number of microplastic particles and the volume of water sampled [49,50]. Hence, the volume sampled is the main factor. Since this study uses a consistent volume of 1000 L in triplicate and the same mesh size, it ensures a direct and comparable assessment of microplastic abundance. In contrast to the results of the study by [51], which revealed that the use of aquatic drones has better economic benefits than the manta trawl method does, compared with the in situ pump method, the microplastic abundance was 10 times greater because the volume sampled was lower than that of the other methods [51]. The abundance of microplastics is generally lower with larger sample sizes, suggesting that smaller sample sizes may be overestimated [47,50,52,53]. Volume samples of 1 m³ [50] and 8 m³ [41] were studied and found to be adequate for the pump method. Moreover, for grab sampling, a sample volume exceeding 500 mL or 1000 mL may provide sufficient accuracy, interquartile range (IQR), coefficient of variation, and recovery rates [54].

3.4. Characteristics of the Microplastics

The characteristics of microplastics, such as shape, color, size, and polymer identification, can provide insights into their potential sources. The microplastic characteristics discussed are based on the total number of microplastic particles collected across all the sampling sites and three sampling methods ($n = 44$; Umeda = 28; Toyo = 4; Yagyu = 12). The microplastics were classified into four shapes (film, fragment, foam, and fiber), seven colors (black, white, transparent, brown, red, green, and blue), and three size categories (500–1000 μm , 1000–3000 μm , 3000–5000 μm) to provide comprehensive insight into the microplastics in this study (Supplementary Figure S4). According to the shape composition (Figure 4), the primary shape had 53% fragments in the plankton net, 56% film in the bucket, and 72% film in the pump method. The results of the Kruskal–Wallis analysis revealed that the sampling method did not significantly influence microplastic shape ($p = 0.93$). This pattern was consistent across individual study sites, as no significant differences in shape distribution were found among the three methods at Umeda ($p = 0.97$), Toyo ($p = 0.56$), or Yagyu ($p = 0.95$), suggesting that microplastic shapes were consistent across sampling methods.

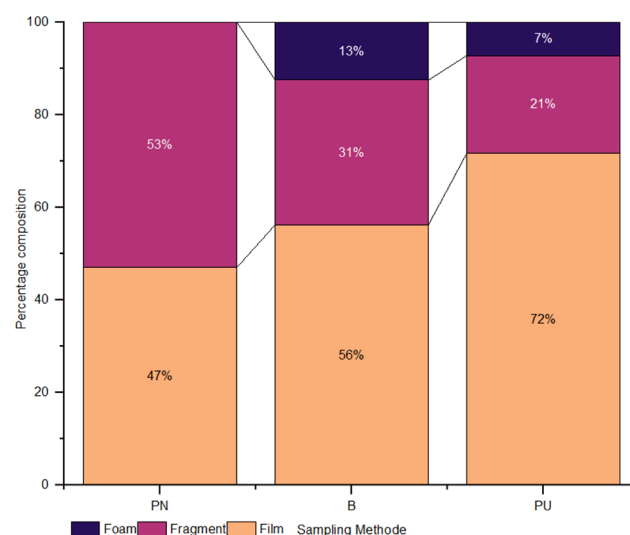


Figure 4. Shape distribution of samples between sampling methods.

The shape indicates potential sources of microplastics [55]. Film microplastics are thin plastic particles that may originate from plastic bags, wrappers, or sheeting [56]. Expanded polystyrene from single-use packaging is likely the source of [56–59]. Foam particles were scarcely detected, while film and fragment morphologies were the most prevalent across all the sampling methods. In the plankton net sample procedure, foam particles were not

detected. The bucket-and-pump method could increase the likelihood of capturing floating foam particles by collecting water from multiple directions. In contrast, the plankton net was operated in a stable, unidirectional manner, indicating that it was likely sampled from relatively consistent and potentially stagnant surface flow. In contrast, plankton net sampling more strongly captured the shape of microplastics than bucket and pump sampling did because of the difference in volume sampled [18].

White microplastics were the most prevalent across all the sampling methods, indicating their widespread distribution in the river systems (illustrated in Figure 5). In Japan, white plastic bags, often characterized as milky white or semitransparent polyethylene, are widely utilized across multiple sectors, including retail, waste management, and packaging [59]. These bags serve various functions, such as shopping carriers, waste collection containers, and storage purposes. The statistical analysis reveals that the sampling methods did not significantly influence microplastic color ($p = 0.77$). Site-specific analyses further supported this result, with no significant differences detected at Umeda ($p = 0.66$), Toyo ($p = 0.52$), or Yagyu ($p = 0.26$), indicating that the distribution of microplastic color was consistent across different sampling methods.

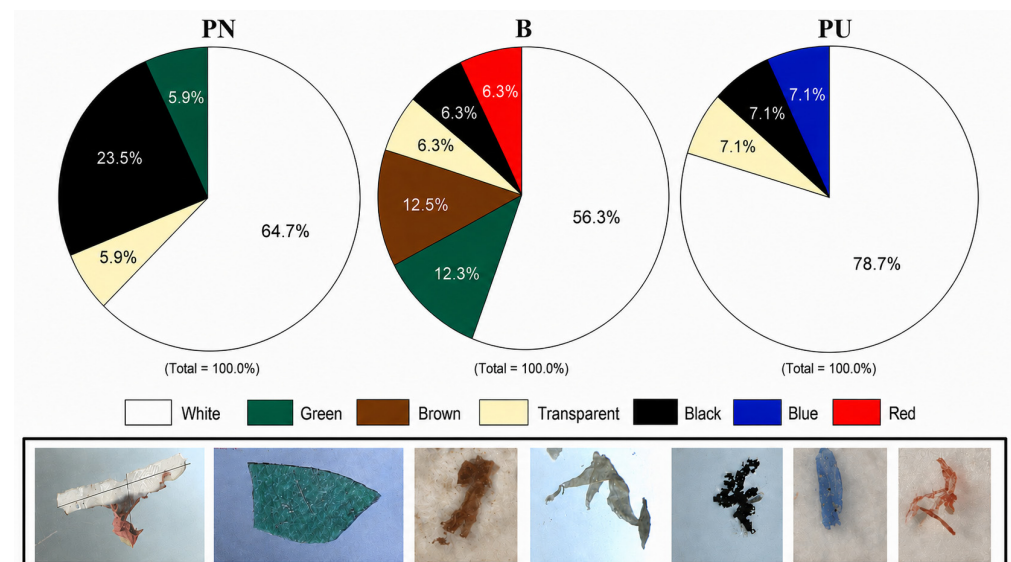


Figure 5. Color composition and representative microplastics identified in the study area.

As shown in Figure 6, in terms of number, the pump and plankton net methods are more efficient for capturing small microplastic particles (300–1000 μm), with efficiencies of 53% and 57%, respectively. However, they are not effective for capturing larger particles. In contrast, the bucket method is more suitable for collecting medium-sized (1000–3000 μm) and large (3000–5000 μm) microplastics, demonstrating its effectiveness for larger particle sizes. Pump sampling has been demonstrated to be particularly effective for capturing smaller microplastic particles than net-based sampling methods, which tend to miss these finer particles [29,60,61]. However, similar to color and shape, the results of the Kruskal–Wallis test indicated that the sampling method had no significant effect on the microplastic size distribution ($p = 0.68$); this finding was consistent across all study sites: Umeda ($p = 0.58$), Toyo ($p = 0.36$), and Yagyu ($p = 0.28$). Implying that while certain methods may show trends in capturing specific size ranges, the variations observed are not statistically significant.

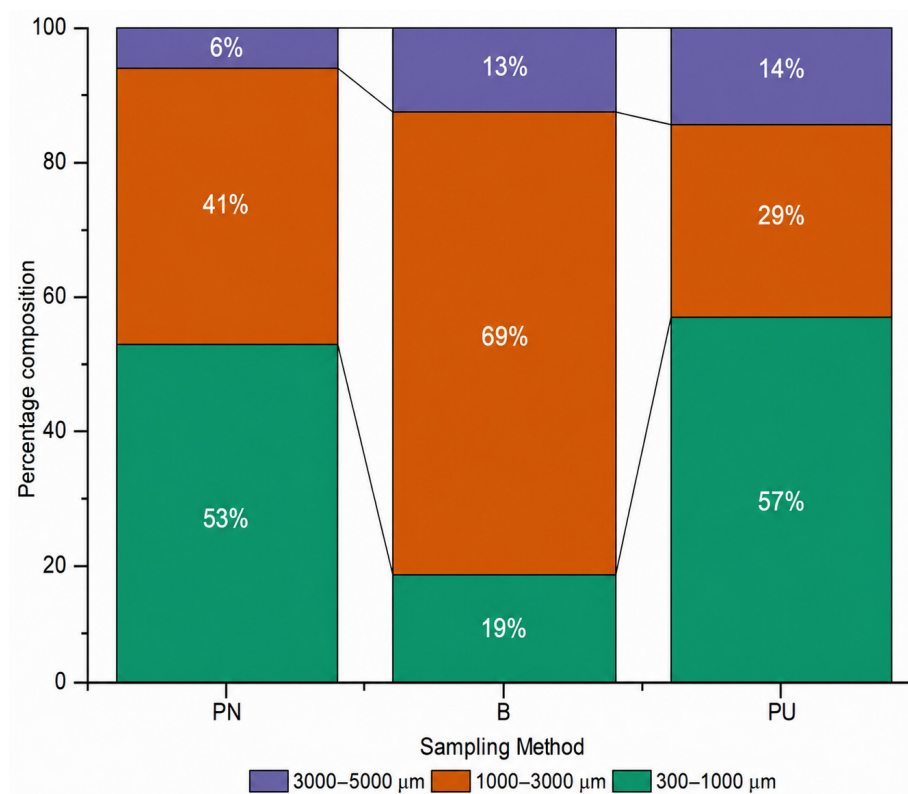


Figure 6. Microplastics categorized by size and composition and captured using different sampling methods.

Regardless of the study area, the predominant microplastic polymers were PP (24–43%) and PE (38–50%) (see Figure 7). This is because PP and PE have low density and high buoyancy and easily migrate with water, and these polymers are usually used in the manufacturing of films, packaging bags, and containers [53]. Moreover, the sampling method did not significantly influence the microplastic polymer type ($p = 0.81$). Moreover, analyzed by site, no significant differences in polymer composition were observed among the three methods at Umeda ($p = 0.91$), Toyogawa ($p = 0.55$), or Yagyu River ($p = 0.57$).

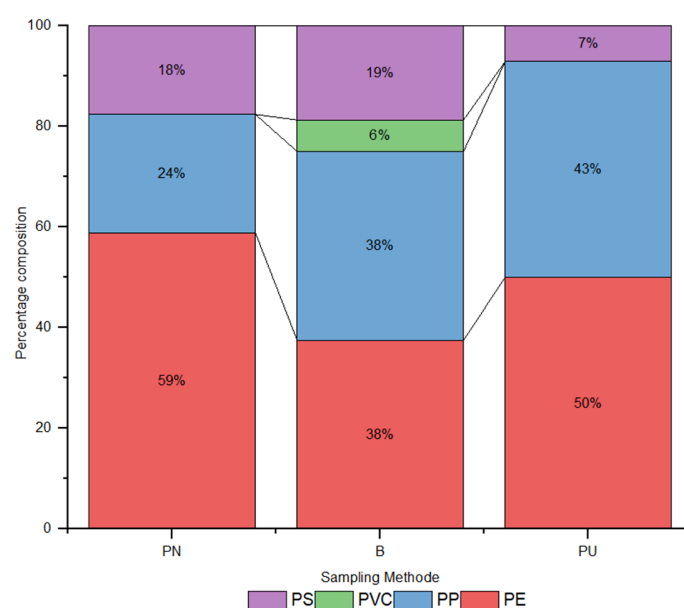


Figure 7. Microplastic abundance based on polymer characterization captured using different sampling methods.

Our results suggest that, based on the number of microplastics captured, the bucket method tends to capture various polymers, shapes, and colors; moreover, the pump demonstrated a greater capacity for capturing smaller particles. When a sampling method is chosen, it is important to first define the specific research objective and/or target of interest and ensure that the chosen method accurately samples it. Many studies using multiple sampling approaches can offer broader insights, enabling a more comprehensive understanding of microplastic pollution [18]. Nevertheless, the overall abundance of microplastics in this study was relatively low. Hence, a greater quantity of microplastics is needed to ensure that the analysis of their characteristics across the three sampling methods is more representative and statistically robust.

3.5. Comparison with Other Studies

The abundance of microplastics in freshwater varies widely across studies and differs by several orders of magnitude globally [62,63]. To compare these data, Table 3 presents a literature review of microplastic abundance and characteristics observed in surface waters, particularly in rivers, with data gathered using diverse sampling methods. Different microplastic sampling methods yielded different abundances of microplastics due to variations in the volume processed and the efficacy of filtration. Pump-based sampling, compared to direct filtration methods, such as plankton nets or manta trawls, reported that pumps are more effective at capturing microplastics than direct filtration methods [41,51,52]. The results of these studies indicate that compared with direct filtration methods, pumps tend to capture more microplastics. This contradicts the results of the current study, which showed no significant differences among the three sampling methods. The increased efficacy of pump-based sampling can be attributed to its ability to process larger volumes of water and capture lighter microplastic particles that would otherwise bypass the mesh-size limitations of plankton nets [63].

It is also noteworthy that studies employing the grab method, such as by using a bucket or a glass bottle, exhibited considerable variation in MP abundance even when filtered volumes were relatively small (<20 L). For instance, substantially higher MP concentrations of 110,000 and 151,000 particles/m³ [64,65] were reported despite processing only 0.5 L and 15 L, respectively—volumes far lower than the 1000 L used in the present study. This disparity suggests that differences in reported abundance cannot be attributed solely to sampling volume but are also strongly influenced by filter/mesh size, as well as broader contextual factors, including plastic waste management infrastructure, anthropogenic activities, and land use characteristics of the surrounding catchment [66,67].

The abundance of microplastics in the Umeda River in Japan is comparable to that in the Snake and Lower Columbia Rivers in the United States, while [17]/share similar potential sources of microplastic pollution from agricultural runoff. Its abundance is approximately 50% of that of the River Ofanto in Italy [8] and three times less than that of the Qin River in China [53]. These discrepancies may be influenced by variations in hydrology [67], agricultural practices [21], and sampling methods [54]. Conversely, in the Toyo River and Umeda River, the microplastic concentration measured with the plankton net method exceeded that measured by pump filtration, matching findings in Gullmar Fjord, Sweden. The variation observed across several studies is often attributed to differences in the volume of water examined [52]. This analysis standardized the sample volume, indicating that the observed discrepancies are likely due to differences in sampling depth or position [68].

Table 3. Comparison of microplastic abundance and characteristics of river surface water globally.

(a) Plankton Net Methods						
Study Area	Sampling Tools Specification	Volume (L)	Abundance (Particles/m ³)	Dominant Microplastics	Potential Sources	Reference
Umeda River, Japan	0.3 m Ø, 300 µm mesh size	1000	2.67	Fragment, PE, 1000–3000 µm	Surface runoff from agricultural land	This study
Toyo River, Japan	0.3 m Ø, 300 µm mesh size	1000	1.00	Film, PE, 300–1000 µm	Urban runoff	This study
Yagyu River, Japan	0.3 m Ø, 300 µm mesh size	1000	1.18	Fragment& Film, PE, 300–1000 µm	Urban runoff	This study
River Saigon and canals, Vietnam	300 µm mesh size	N/A	10	Fragments, PE, PP, 1000–5000 µm	Industrial and sewage effluent litter degradation	[69]
Karnaphuli River Estuary, Bangladesh	300 µm mesh size	N/A	4.86	Film, PP, PS, PET, 1000–5000 µm	Shipping, domestic, industry run off	[70]
River Qin, China	0.2 m Ø	7800–160,500	5.6	Fragments, PE, PP, 1000–5000 µm	Aquaculture, sewage effluent (point source)	[53]
Snake and lower Columbia River, United States	0.25 m Ø, 100 µm mesh size	3207	34,285	Fragments, PE, PP, 1000–5000 µm	Surface runoff from agricultural lands	[17]
River Ofanto, Italy	0.45 m Ø, 333 µm mesh size	N/A	6.95	Fragments, PE, PP, 1000–5000 µm	Surface runoff from agricultural lands	[8]
Liane River, France	333 µm mesh size	35,000	23.27	Film, PP, PS, PET, 1000–5000 µm	Wastewater treatment effluent, Urban Runoff	[51]
Liane River, France	Aquatic Drone 333 µm mesh size	32,300	23.27	Fibers, PE and PP, <1000 µm	Wastewater treatment effluent, Urban Runoff	[51]
Gullmar fjord on the Swedish	0.6 m Ø, 300 µm mesh size	20,000	0.51	Fragment, LDPE, 300–500 µm	N/A	[52]
(b) Bucket Method						
Study Area	Sampling Tools Specification	Volume (L)	Abundance (Particles/m ³)	Dominant Microplastics	Potential Sources	Reference
Umeda River, Japan	Stainless steel	1000	3.67	Film, PP, 1000–3000 µm	Surface runoff from agricultural land	This study
Toyo River, Japan	Stainless steel	1000	0.00	N/A	Urban runoff	This study
Yagyu River, Japan	Stainless steel	1000	0.98	Film, PE, 300–3000 µm	Urban runoff	This study
Yellow River, China	Stainless steel	60	11.42	Fibers, PE & PP, <1000 µm	Agriculture	[21]
River Saigon and canals, Vietnam	N/A	300	172,000	Fibers, PE, <1000 µm	Industrial and sewage effluent litter degradation	[69]
Snake and lower Columbia River, United States	Glass jar	1.85	0.2705	Fibers, PE, PP, <1000 µm	Surface runoff from agricultural lands	[17]
Sierra Gorda Biosphere Reserve	Glass containers	0.5	4350–110,000	Fibers, PET	Domestic activities	[64]
Gulf Mexico	Glass containers	15	151,000	Fibers PE, PET	Domestic activities	[71]
(c) Pump method						
Study Area	Sampling Tools Specification	Volume (L)	Abundance (Particles/m ³)	Dominant Microplastics	Potential Sources	Reference
Umeda River, Japan	Centrifugal	1000	3.00	Film, PE&PP, 300–1000 µm	Surface runoff from agricultural land	This study
Toyo River, Japan	Centrifugal	1000	0.33	Film, PE, 1000–3000 µm	Urban runoff	This study
Yagyu River, Japan	Centrifugal	1000	1.27	Film, PE & PP, 300–1000 µm	Urban runoff	This study
Dutch riverine	Centrifugal	1300–8000	862	Fibers, PE & PP, <100 µm	Run off from urban and wastewater treatment plant effluents	[72]
River Qin, China	Teflon	20	16.67	Fibers, PE, PP, 1000–5000 µm	Aquaculture, sewage effluent (point source)	[53]

Table 3. Cont.

Study Area	Sampling Tools Specification	Volume (L)	(c) Pump method		Potential Sources	Reference
			Abundance (Particles/m ³)	Dominant Microplastics		
Liane River, France	In situ filtration	354	46.75	Fibers, PE and PP, <100 µm	Wastewater treatment effluent, Urban Runoff	[51]
Gullmar fjord on the Swedish	In situ filtration	62,000	0.23	Fragment, LDPE, 300–500 µm	N/A	[52]

N/A: Not available.

3.6. Methodological Constraints and Sampling Method Recommendations

The samples in this study were collected under sunny weather conditions, indicating that environmental conditions did not influence microplastic abundance. Although all methods used the same water volume in this study, variations in the sampling locations were observed. Samples collected using the pump method were generally taken from the riverbanks, except in the Yagyu River, where the wetted width is less than 8 m, and sampling was conducted from the middle of the river. Different sampling methods should be applied at the same location, as variations in sampling position can influence the abundance and characteristics of microplastics.

Net sampling is most suitable for rivers with low pollution levels. In highly polluted rivers, significant amounts of organic (e.g., leaves, branches, and aquatic organisms) and inorganic (e.g., sand and fine sediment) material become trapped in the net, making it more challenging to separate microplastic particles. Techniques such as organic degradation and density separation are less effective, as organic particles, such as leaves, cannot be fully degraded without also affecting plastic particles with the chemicals used. Moreover, density separation is impractical because organic materials float alongside microplastics, concealing them within the sample. In contrast, the pump sampling method yielded exceptionally clean samples because its suction basket prevented particles larger than 50 mm from passing through. As a result, the collected samples required minimal processing before microplastic extraction.

The data in Table 4 represent the recommended sampling methods based on river characteristics (depth, velocity, and width); especially for rivers with depths >300 mm, all the sampling methods are feasible, except when the width of the river is greater than 8 m, and the pump method will require a long hose to reach the middle of the river; hence, the operational cost will be high. However, when the river water depth is less than 300 mm, either the bucket or pump method should be considered, each offering advantages and limitations, as previously discussed. Under high-flow conditions, the plankton net, pump, and bucket methods are all feasible. However, the equipment must be operated from the riverbank or above the river, as entry into the river poses a safety risk for researchers, particularly during rainy events. In the case of the pump method, a long hose is required to reach the river's center, which significantly increases the operational complexity and cost. For field studies involving multiple sampling sites and high sample volumes, the pump method is often preferred for its efficiency in handling and processing samples. Ultimately, selecting the most preferred sampling method should be based on the study's objectives, available resources, and specific environmental conditions. Selection methods also impact the reliability of microplastic research. However, it should be noted that this study was based on three replications per method per site, which may limit the statistical power of the findings; therefore, the results should be interpreted with reasonable caution. Increasing the number of replications in future studies would further strengthen the robustness of the method comparison.

Table 4. Recommended sampling method options based on river characteristics.

River Characteristic			Sampling Method		
Depth	Velocity (m/s)	Width (m)	PN	B	PU
<300 mm	<0.8	<8		•	•
	>0.8	>8		•	
>300 mm	<0.8	<8	•	•	•
	>0.8	>8	•	•	

Note: • = Recommended sampling method for the specified river characteristics.

4. Conclusions

To the best of our knowledge, this study provides the first direct field-based comparison of three commonly used surface water microplastic sampling methods, plankton net, bucket, and pump, conducted simultaneously under standardized volume conditions (1000 L) in low-flow and shallow riverine environments (depth < 30 cm; velocity < 0.1 m/s), which remain critically underrepresented in the existing microplastic sampling literature. We demonstrated that all three methods yielded statistically comparable microplastic abundance and characteristics, including shape, color, size class, and polymer type, across three rivers with contrasting catchment characteristics (Kruskal–Wallis, all $p > 0.05$), indicating that no single method introduces differences under such constrained hydrological conditions. We further revealed that while statistical equivalence exists among the methods, their operational applicability differs substantially: bucket sampling demonstrated the greatest practical flexibility across varying low-flow conditions; pump sampling excelled at capturing greater volumes; and plankton net performance was compromised in rivers where full submergence could not be achieved. Additionally, we showed that site-specific catchment characteristics—rather than the choice of sampling method—were the primary driver of differences in microplastic abundance and typological diversity across study sites, with the Umeda River exhibiting the highest abundance, possibly due to its plastic usage within the catchment area. Ultimately, this study provides a practical foundation for developing context-sensitive microplastic sampling guidelines for low-flow river systems, supporting a methodologically adaptive framework in which site-specific river characteristics guide method selection to improve the accuracy, comparability, and representativeness of riverine microplastic monitoring.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app16136684/s1>. Figure S1: Cross-sectional diagram of the Umeda River, as viewed facing the direction of water flow. The riverbed depths are indicated for 6 September 2024. Figure S2: Cross-sectional diagram of the Toyo River, as viewed facing the direction of water flow. The riverbed depths are indicated for 24 September 2024. Figure S3: Cross-sectional diagram of the Yagyu River, as viewed facing the direction of water flow. The riverbed depths are indicated for 26 September 2024. Figure S4: Average microplastic abundance (particles/m³) categorized by (a) size class (300–1000 µm, 1000–3000 µm, and 3000–5000 µm), (b) polymer type (PE, PP, PVC, and PS), and (c) color across three sampling methods—Plankton Net (PN), Bucket (B), and Pump (PU)—at the Umeda, Toyo, and Yagyu Rivers. Error bars represent standard deviation. No significant differences were observed among sampling methods for any category at any site (Kruskal–Wallis, $p > 0.05$). Table S1: Microplastic Sampling Quality Criteria (Lofty et al., 2023) [30]. Table S2: Quality assessment scores of the current study based on the Microplastic Sampling Quality Criteria. Reference [73] is cited in the supplementary materials.

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