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Original Research

Depth-Wise Distribution of Microplastics in Around Teluk Lerong In-take, the Mahakam River: Implications for Water Treatment Processes

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Abstract: The Mahakam River is an essential raw water source for WTP in the Regional Drinking Water Company of Samarinda City. This means its quality is crucial, specifically due to several actiities usually conducted in the river and the density of the surrounding community. One of the most critical issues related to surface water quality is microplastics. This study aimed to assess the abundance, size, and types of microplastics present in the water column of river at various depth levels. Samples were collected from intake using a composite sampling method. The samples were processed by first filtering with a 180 µm nylon, removing organic substances with H_2O_2, separating by density, conducting a second filtration with different nylon sieves, and then performing microscopic observation. The identification of polymers was carried out using FTIR. The results indicated the presence of microplastics in all tested samples. The highest abundance of microplastics, 25.4 particles per liter, was in the size range of 180 µm - 250 µm at a depth of 0.5 meters. The abundance of microplastics decreased as the depth of the river increased. The most common type of microplastic detected was fiber, fragments and films. It is crucial to map the distribution of microplastics, mitigate their occurrence, and reduce degradation and fragmentation to increase WTP perform.

Key Words	abundance; fiber; film; fragment; microplastic; river; WTP
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1. INTRODUCTION

The Mahakam River is the second-longest river in Indonesia, flowing through several regencies and cities such as Samarinda City, Kutai Kartanegara Regency, and West Kutai Regency. It has a length and area of 920 km and 149,277 km^2, respectively, (Badan Pusat Statisik, 2014) and is reported to be the source for 13 rivers and supplies several lakes along the rivers, such as Jempang, Semayang, and Melintang Lakes (Noor et al., 2013). The essential function of the river to the people of Samarinda City is related to its usage as the main source of the raw water used by the PDAM's WTP, which has more than 156,278 customers (BPS, 2019). It is important to note that the Cendana WTP has the most significant supply and utilizes the raw water of the Mahakam River through Lerong Bay Intake.

This means it is essential to determine the quality of this river due to the effect of raw water on processed products. It is pertinent to understand that the quality also depends on the watershed. However, the Mahakam River watershed is located in an area with several domestic, commercial, and industrial activities, which means it is vulnerable to both intentional and unintentional dumping of liquid and solid wastes. This is indicated by the habit of some residents throwing garbage into the river (Dewi, 2016), which accumulates and causes silts (Tambunan, 2014). Therefore, monitoring the raw water's physical, chemical, and biological quality is crucial to ensure that the treated water produced is safe for consumption. Meanwhile, one of the critical issues usually related to surface water quality, which requires adequate monitoring, is microplastic content, even though there has been no regulation concerning acceptable standards up to the present time. Microplastic is the smallest part of plastic experiencing degradation through the physical, mechanical, and biological fragmentation process (Corcoran, 2021) (Klein et al., 2018), and also usually < 5 mm in size (Azizah, Ridlo and Suryono, 2020) (Ayuningtyas, 2019). It was further divided into macro-plastics, meso-plastics (large microplastics), microplastics (small microplastics), and nano-plastics with a size of > 5.00 mm, ≤ 5 - >1 mm, ≤ 1mm - > 0.1µm, and ≤ 0.1µm, respectively (Azizah, Ridlo and Suryono, 2020) [14-17]0.This is necessary because the rivers in urban areas typically have the potential to contain higher microplastics, which are transported upstream (McCormick et al., 2016) to the seashore (Łabuz, 2021).

However, there are limitations to research on the freshwater environment ((Wagner et al., 2014) (Bellasi et al., 2020), so monitoring, fate, and transport of the microplastic presence need to research in the upstream areas, namely lakes and rivers (Rogowska et al., 2021). The presence of microplastics in surface water can be caused by the solid wastes dumped into the river based on the activities in the watershed. This was confirmed by the findings of Scherer et al. (Scherer et al., 2020) that the high microplastic content in the water and sediment samples originated from industrial activities. Harpah et al. (Harpah et al., 2020) also reported that microplastics in Sei Sikambing River, Medan, were due to domestic or household wastes. Additionally, the highest levels of microplastic contamination were found in water treatment plants that utilized raw water from rivers near industrial areas and densely populated regions that discharged untreated domestic waste (Pivokonsky et al., 2018). The presence of microplastic wastes in the sea and freshwater has become a crucial issue in recent years.

Some recent research showed that different types and sizes of microplastics are present in several water areas in Indonesia, as indicated by those found in water (Ayuningtyas, 2019) (Kapo, Toruan and Paulus, 2020), (Sutanhaji, Rahadi and Firdausi, 2021) (Sembiring et al., 2020) (Alam et al., 2019a), water sedimentation (Azizah, Ridlo and Suryono, 2020) (Firdaus, Trihadiningrum and Lestari, 2020) (Sembiring et al., 2020) (Alam et al., 2019a), aquatic biota (Bahri et al., 2020) (Sembiring et al., 2020), (Yudhantari, Hendrawan and Puspitha, 2019), and aquatic product samples such as salt. Furthermore, Shen *et al.* (Shen et al., 2020) also showed that microplastics detected in freshwater worldwide ranged between zero and millions of particles per cubic meter.

Several previous studies discussed the depth factor (Lestari et al., 2020), which shows that microplastics particles tend to be distributed on the surface column of rivers., Research (Wijaya and Trihadiningrum, 2019) analyzing vertical and horizontal distributions where vertically it tends to fluctuate, and research (Alam et al., 2019b) examines the distribution of MPs in river water and sediment samples. Research by (Napper et al., 2023) analyzes microplastic with the distribution of MPS in air, water, and sediment. However, these studies have not analyzed in detail the effect of depth factors on the abundance and size of microplastics. It is important to note that microplastics contained in raw water can be carried out into WTP and subsequently into the drinking water supply system for public consumption. This was also confirmed by research by Pivokonsky et al. (Pivokonsky et al., 2018) conducted in the Czech Republic and (Ferraz et al., 2020) in Brazil, which proved the presence of microplastic contamination in raw and treated water. This means the conventional WTP cannot remove microplastics from raw water effectively, thereby causing disruptions in human health with several risks such as toxic effects, nerve damage, chronic inflammation (Kumar et al., 2021) (Liu et al., 2020) through exposure to bioaccumulated food chains as well as biomagnification, water consumption, and others (Wong et al., 2020) (Akdogan and Guven, 2019).

This means it is necessary to conduct this research to determine microplastics' presence in the Mahakam River. The process involved identifying the raw water from Mahakam River retrieved from The Teluk Lerong intake and to be used in WTP. Moreover, microplastics' abundance, type, and size were analyzed based on the river depth.

2. MATERIALS AND METHODS

Overview of the water sampling, sample preparation, microplastic abundance calculation, and identifiction methods used in the study of microplasctic at Mahakam River water samples. The methods refers to the NOAA microplastic analysis standards (NOAA, 2015). 2015) which are also referred by several researchers : (Lestari et al., 2020)(Eamrat, Taweesan and Pussayanavin, 2022)(Rodrigues et al., 2018)(Sharma, 2019)(Ayuningtyas, 2019)

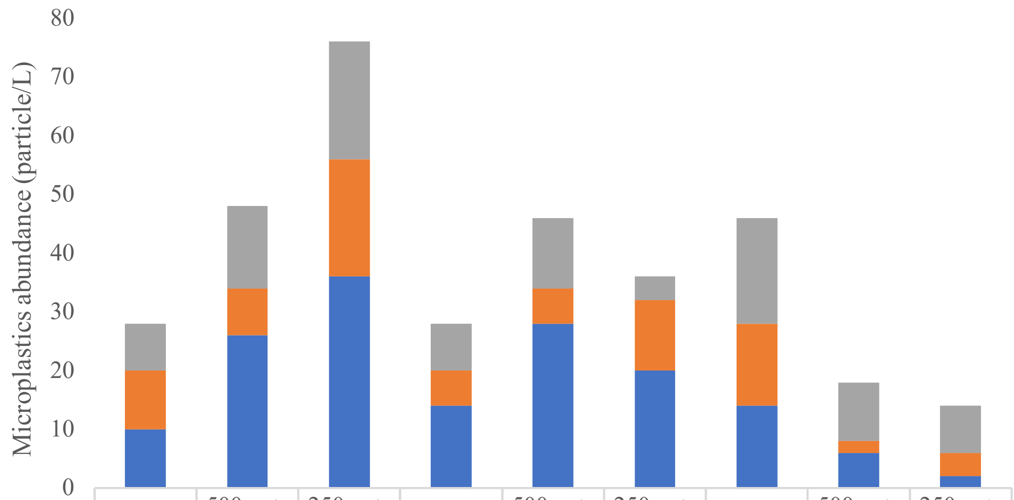
Process	Details
Water Sampling (Pivokonsky et al., 2018), (Standar nasional Indonesia, 2004)	- Location: Mahakam River, Teluk Lerong Intake (Cendana WTP) - Sampling Frequency: Three times in 24 hours (every 8 hours) - Depths: 0.5, 1, and 1.5 meters - Total Volume: 9 liters (composite sample) - Method: Grab sampling (1-liter samples) - Equipment : The horizontal van Dorn water sampler system is a sturdy transparent tube with a double cover and a durable steel release system. This tool is suitable for sampling in rivers with different depths horizontally
Sample Preparation	- Initial Filtering: 500 mL filtered through a 180 μm nylon sieve with a vacuum pump - Heating: Sieve placed in porcelain dish, covered with aluminum foil, heated at 90°C for 24 hours - Residue Transfer: Solid transferred to a beaker with distilled water - Dissolving Organic Matter: 20 mL of 0.05 M Fe(II) and 20 mL of 30% H_2O_2 added, left for 5 minutes (Pico, Alfarhan and Barcelo, 2019) - Heating: Beaker heated at 75°C until organic matter disappears (NOAA, 2015) - NaCl Addition: 6 g of NaCl per 20 mL sample added and stirred at 75°C - Density Separation: Sample placed in density separator for 24 hours; solids removed, remaining water and microplastics transferred to a beaker - Filtration: Filtered using nylon sieves (500 μm, 250 μm, 180 μm) in petri dishes (Ayuningtyas, 2019). - Contamination prevention measures are by limiting exposure of sample materials to MP sources, such as air, synthetic textiles, and plastic materials. Nylon materials are rinsed several times with distilled water. Samples should be covered between use and polymer free clothing use be worn while performing tests
Microplastic Abundance Calculation	Microplastic abundance calculated using the formula: $Microplastic\ abundance = \frac{\text{number of microplastic particles (particles)}}{\text{volume of filtered water } (\text{m}^3)}$ - Calculated for each size category (500 μm, >500 μm to 250 μm, >250 μm to 180 μm) - Data collected three times to analyze the effect of sieve size and depth on microplastic abundance. - Due to the data distribution being normal (RJ 0,95, P-value 0,059 > 0,05), a correlation test was used to determine the influence of depth on the abundance and size of microplastics

Identification of Microplastic Types	- Microplastics identified based on shape observed under a microscope (Azizah, Ridlo and Suryono, 2020), (Hanif, Suprijanto and Pratikto, 2021): Fiber: Elongated shape, Film: Transparent, thin, soft, Fragment: Hard, rigid - Analysis Method: FTIR analysis used to determine polymer types (e.g., PP, PE, PVC) (Shim, Hong and Eo, 2017) by comparing spectra with known sample

3. RESULTS AND DISCUSSIONS

3.1. Microplastic Abundance Based on Depth and Size

The results showed that all the water samples from Mahakam River were contaminated by microplastics that ranged between 500 µm, 500 µm> x 250 µm, and 250 µm> x ≥180 µm at different depths, as shown in **Figure 1**. It was discovered that the highest were those between 250 µm> x 180 µm with an average abundance of 25.4 particles/L found at a depth of 0.5 m. This means the smaller microplastics are found on the river's surface while the bigger ones that are >500 µm are lesser and found in the deeper part. The abundance was observed to decrease as the size and depth of the river increased, as indicated in **Figure 1**.



	0.5 meter			1 meter			1.5 meter		
	≥500µm	500µm> - ≥250µm	250µm> - ≥180µm	≥500µm	500µm> - ≥250µm	250µm> - ≥180µm	≥500µm	500µm> - ≥250µm	250µm> - ≥180µm
Sampling 3	8	14	20	8	12	4	18	10	8
Sampling 2	10	8	20	6	6	12	14	2	4
Sampling 1	10	26	36	14	28	20	14	6	2

Figure 1. The Abundance of Microplastic refers to The Size and Depth of River

Microplastic sampling occurred in August during the rainy season, which typically increases the runoff of microplastics from land into rivers, either directly or through drainage systems. Lighter particles tend to float on the water's surface, while heavier ones either settle in sediments or remain on land (Nizzetto et al., 2016). The Mahakam River, bordered by urban areas, faces a higher risk of microplastic contamination. This observation aligns with previous studies that indicate urbanization, characterized by high population density and activity, significantly impacts the presence and abundance of microplastics in aquatic environments. (Horton et al., 2017) (Sari et al., 2021). Similar findings were reported in research conducted on Indian rivers, which explored various types of anthropogenic influences in both urban and rural contexts (Lechthaler et al., 2021).

3.2. Microplastic Abundance by Types

Microscopic analysis revealed the presence of three types of microplastics in water samples from the Mahakam River, as illustrated in Figure 2. The fiber types resemble lines and threads, while the film types have irregular shapes, are thin, and transparent. In contrast, the fragment types are solid, have jagged edges, and appear as pieces of larger plastics (McCormick et al., 2016). The fiber types were the most common in the sample for all the sizes and depths. Among these, fiber types were the most prevalent across all sample sizes and depths. Microplastic fiber types were identified in every sample across all size categories: ≥500 µm, 500 µm > x ≥ 250 µm, and 250 µm > x ≥ 180 µm. They were most frequently found in samples taken from a depth of 0.5 meters, with an average concentration of 48.67 particles per liter. The lowest abundance of microplastic fiber was at a depth of 1.5m, namely 26 particles/L (**Figure 2**). The presence of this type of microplastic fiber will decrease with increasing depth according to the abundance found. Meanwhile, fragments were only found at a depth of 0.5m and films at depths of 0.5m and 1m in small quantities.

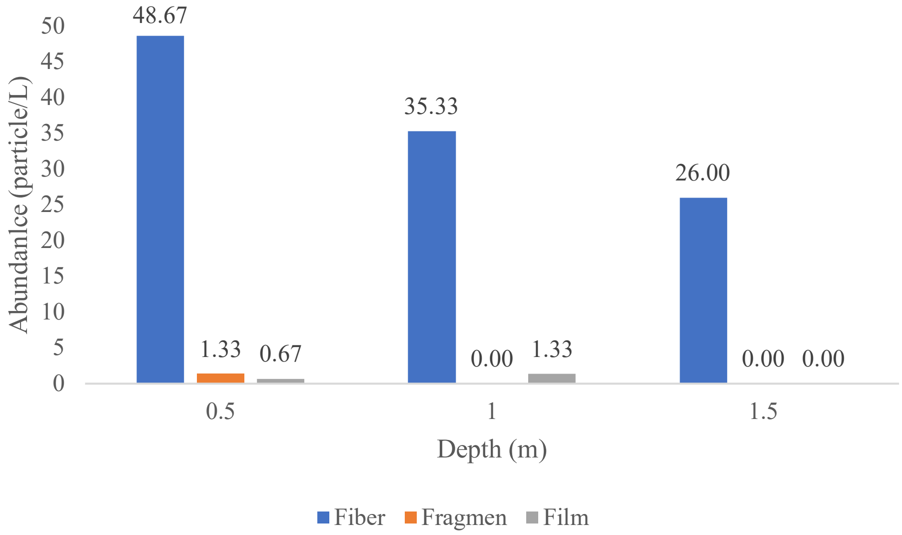


Figure 2. The abundance of microplastic refers to the type and depth of the river

The fiber types of microplastics are thin and long, which makes them resemble synthetic fibers (Ayuningtyas, 2019). Most of them are observed to have originated from domestic wastes such as water used in washing clothes and household appliances dumped into rivers. The fiber type of microscopics is presented in **Figure 3**.

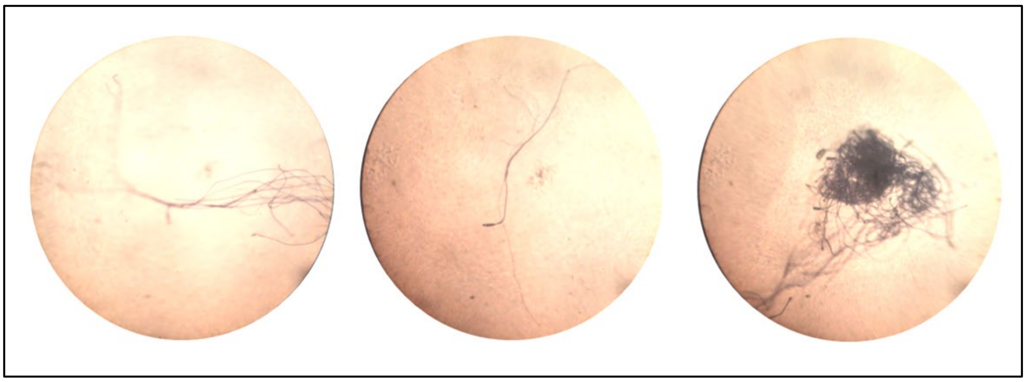


Figure 3. The Type of Fiber Microplastics

Researchers also showed that fiber is the dominant type of microplastic (Malla-Pradhan et al., 2023), approximately 45% at all levels of the water column (Lenaker et al., 2019). This was also recorded in research conducted at several locations in Indonesia that fiber as the dominant microplastic compared to other types (Alam and Rachmawati, 2020) (Sutanhaji, Rahadi and Firdausi, 2021)(Tuhumury and Pellaupessy, 2021)(Yudhantari, Hendrawan and Puspitha, 2019)(Firdaus, Trihadiningrum and Lestari, 2020)(Alam et al., 2019a)(Kapo, Toruan and Paulus, 2020)(Yona et al., 2022)(Nurwahyunani and

Rakhmawati, 2022). The high amount of fiber found may have come from the degradation of clothing (textile synthetics) due to the washing process (Wagner and Lambert, 2018) (Bellasi et al., 2020)(Lambert, Boxall and Sinclair, 2014). Moreover, this was generally dominated by polyester and nylon (Horton et al., 2017). Moreover, in Indonesia, mainly through drainage systems where not all domestic sewage wastewater has been treated at the WWTP, it flows directly into the river (Alam and Rachmawati, 2020). Thus, it is possible to find many fiber microplastics in rivers. This is related to research (Piskuła and Astel, 2022), in which the number of existing microplastics in river water is higher in the downstream part of the WWTP.

The films are the transparent and thin microplastics (Azizah, Ridlo and Suryono, 2020). They were observed to be present at 0.5 and 1-meter depth, which is also classified as the water surface area because they have low density. Their sizes were discovered to range between 250 µm and 180 µm and generally include plastic bags or other thin plastic materials. The microscopic observation of the film type of microplastics is presented in **Figure 4**.

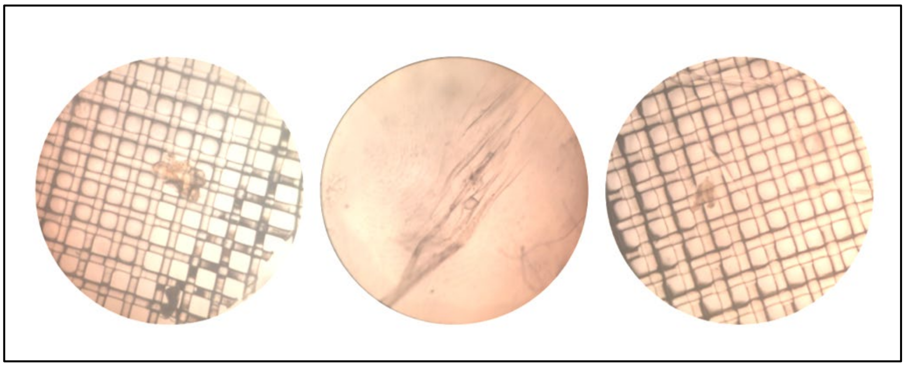


Figure 4. Film Microplastics

The fragments are opaque, thick, and hard microplastics that typically originate from larger plastic waste, such as bottles and pipes (Ayuningtyas, 2019) [16]. They were only detected in the 180 µm size category at a depth of 0.5 meters, which corresponds to the water's surface (**Figure 5**). This is because plastics on surface land are often exposed to sunlight and high temperatures, accelerating the fragmentation process In contrast, fragments made from denser polymers are likely to remain in the soil and migrate to deeper layers, while those from lighter polymers can be carried by wind or water to the water's surface. The Fragmentation can also occur in aquatic environments due to UV exposure from sunlight and wave action, a process that is similarly applicable to film-type microplastics (Horton et al., 2017). A study by Seyfi et al.(2021), found that fragment and film microplastics were present in over 70% of beach sand. Furthermore, the aging process of microplastics enhances their ability to adsorb metals by 20 to 60%. When bacterial cultures are present, this aging process can increase the adsorption capacity for various metals (Pb, Cd, Cu, Cr, Zn, Ni) to around 60-80%.

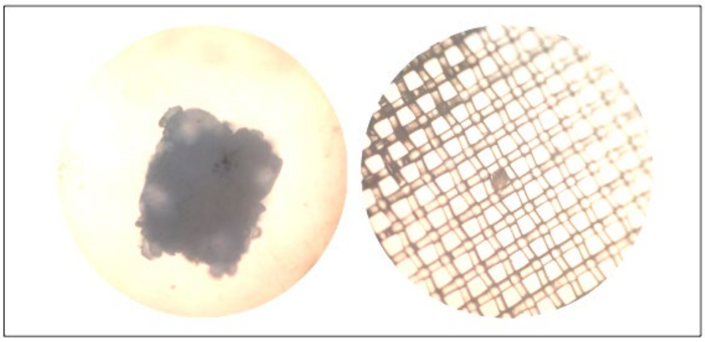


Figure 5. The Type of Fragmen Microplastic

3.3. Effect of The Depth of River Column

This Based on these data, it shows that the microplastics found in the surface area (at a depth of 0.5m) are dominated by small microplastics (250µm> x ≥180µm) with an average of 25.33 particles/L (the regression statistics show an r2 of 0.9626, p-value 0.068). Whereas in the deeper parts (at a depth of 1.5m), large microplastics (> 500µm) are dominant in smaller amounts, namely an average of 15,33 particles/L. The abundance value of microplastics in small sizes will decrease as the depth of the river increases. Meanwhile, the size of microplastic particles was found to be larger with increasing depth, as shown in the graph in **Figure 6** left ordinate. Based on depth, the highest total average microplastic was found in the depth of the water surface area at 0.5m depth, namely 50.67 particles/l, and the lowest abundance at a depth of 1.5m was 26 particles/l. Microplastic abundance will decrease with increasing sampling depth (the regression statistics show an r2 of 0.9939, p-value 0.021), as shown in **Figure 6**, right ordinate.

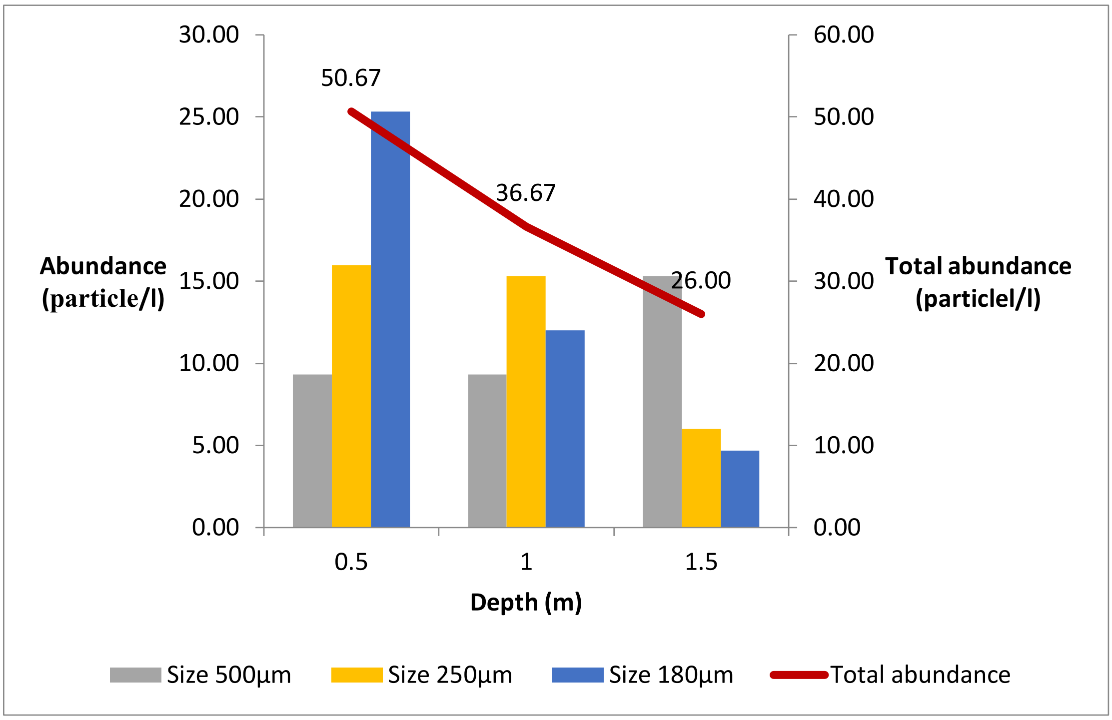


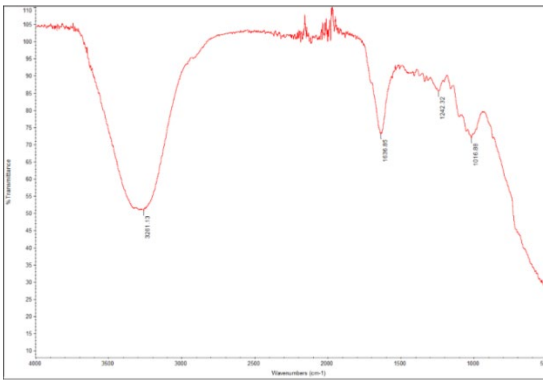
Figure 6. Effect of The Depth of River to Abundance and Size of Microplastic

The findings indicated that the river's surface layer at a 0.5-meter depth contained the highest abundance of microplastic particles, with sizes as small as 250µm> x 180µm (the regression statistics show an r2 of 0.9727 p-value 0,068) , which is associated with their tendency to have smaller densities. Previous studies have shown that the distribution of microplastics in water is influenced by density, with lower-density particles remaining at the surface. In contrast, higher-density people tend to settle in sediments (Horton et al., 2017). A similar pattern was noted by Kankanige (Kankanige and Babel, 2021) that microplastic fractions with a small size (65-53 µm) were prevalent in both untreated and WTP-treated water. Previous research also showed that the density of polymer influenced its presence on the surface, subsurface (middle surface), and bottom of the water (Lestari et al., 2020) (Lenaker et al., 2019). Additionally, factors such as channel depth, stream velocity, and particle type play a role in microplastic distribution throughout the water column (Lenaker et al., 2019).

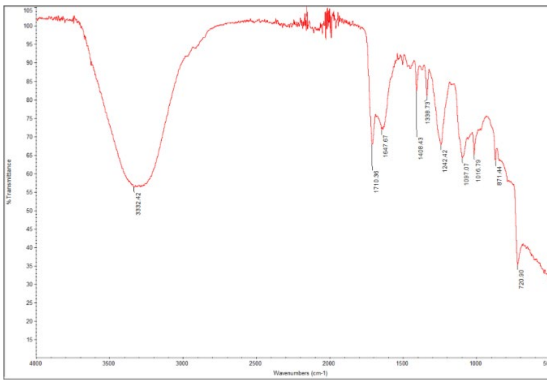
Microplastics can reach the surface water through several routes with the migration from land observed to the primary and most frequent human habits such as dumping of garbage and recycling process, physical forces such as weather conditions including wind, rain, and flood, as well as environmental and topographic conditions (Eerkes-Medrano, Thompson and Aldridge, 2015) (Horton et al., 2017) (Kaliszewicz et al., 2020). The primary source of coastal waste was waste disposed of directly by humans at that location or carried by the river flow. So, more waste is found in coastal areas close to the estuary (Łabuz, 2021). Another factor is river water, a means of transportation and agricultural activities that lead to rivers (Rogowska et al., 2021). The Mahakam River is a river that has the primary function for coal pontoon transportation, transportation of goods, and ecotourism (Susanto and Kiswantoro, 2020)(Tambunan, 2014). Even the heavy traffic of coal pontoon transportation has affected the native animal of the Mahakam River, namely the Pesut Mahakam, which has moved its natural habitat location (Noor et al., 2013). The report confirmed this regarding garbage, which showed that some communities around the Mahakam River dump garbage into the river (Dewi, 2016), thereby causing silting, evidence of waste accumulation (Tambunan, 2014). Moreover, one of the river's tributaries was found to have poor water quality due to the industrial and household activities conducted around its location, which leads to the direct discharge of domestic wastes into the river water. (Pramaningsih, Suprayogi and Setyawan Purnama, 2017). The data further supported this, showing that Mahakam River is moderately to severely polluted (Kemen L.H dan Kehutanan, 2021). Meanwhile, it is recommended that the research on microplastics should also be limited to large rivers such as the Mahakam River and extended to small rivers or tributaries. This is necessary because small rivers in urban areas have been reported to have higher concentrations of microplastics because they act as dumpsites (Dikareva and Simon, 2019).

3.4. Microplastics Polymers Analysis

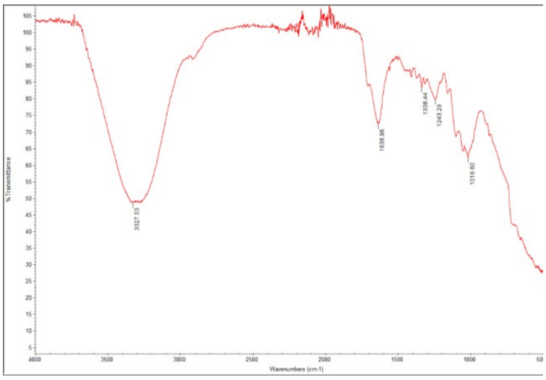
The Identification of the polymer microplastic type using FT-IR produces a wavelength (**Figure 7**) that compares and matches it with the wavelength of the type of reference microplastic. The wave results are compared to the plastic polymer wave, serving as a reference to generate a list of identified polymer types, as shown in T**able 1**.



(a)

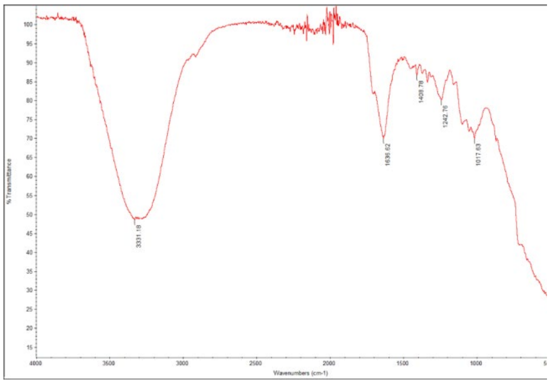


(b)



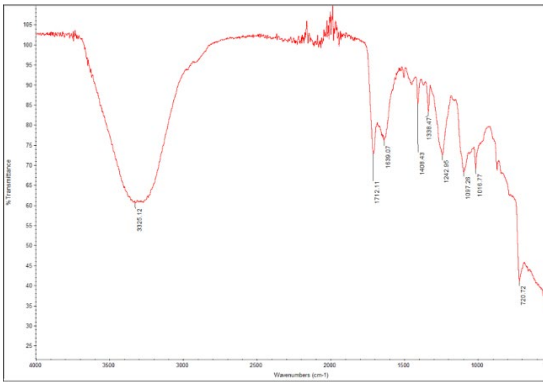
3327.53
1638.96
1338.44
1243.29
1016.60
% Transmittance
Wavenumbers (cm-1)

(c)



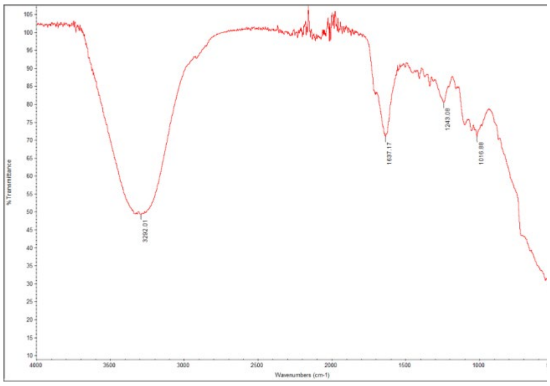
3331.19
1636.62
1408.78
1242.76
1017.63
% Transmittance
Wavenumbers (cm-1)

(d)



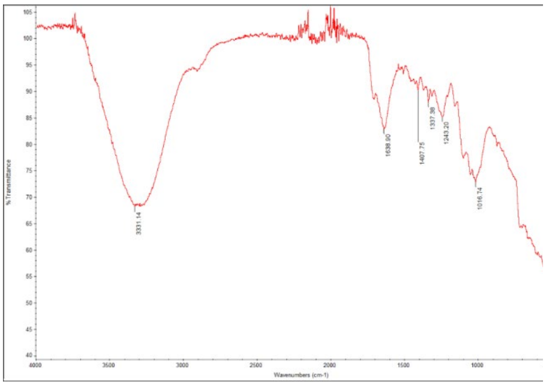
3325.12
1712.11
1639.07
1408.43
1338.47
1242.95
1097.26
1016.77
720.72
% Transmittance
Wavenumbers (cm-1)

(e)



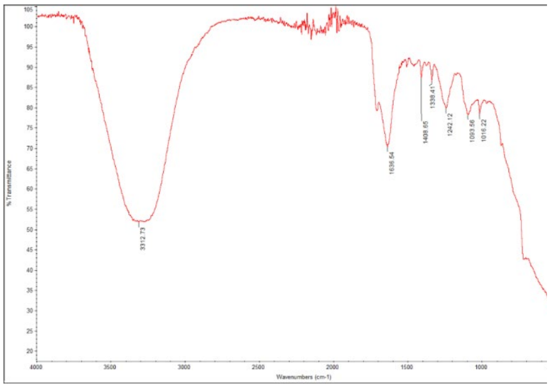
3292.01
1637.17
1243.08
1016.86
% Transmittance
Wavenumbers (cm-1)

(f)



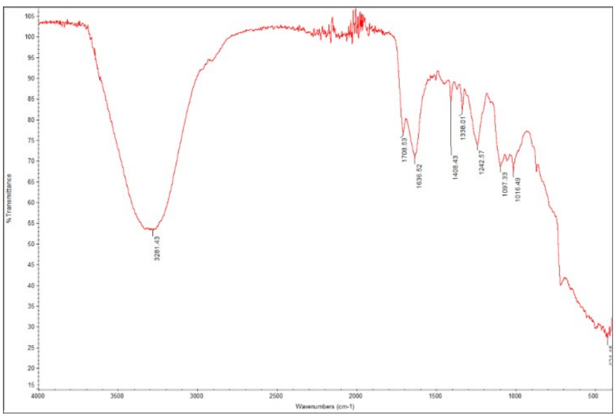
3331.14
1636.90
1407.75
1337.38
1243.20
1016.74
% Transmittance
Wavenumbers (cm-1)

(g)



3312.73
1636.84
1408.65
1338.41
1242.12
1093.56
1016.22
% Transmittance
Wavenumbers (cm-1)

(h)



3281.43
1709.53
1636.52
1408.43
1338.01
1242.57
1097.33
1016.49
% Transmittance
Wavenumbers (cm-1)

(i)

Figure 7. FTIR Spectra Results: (a) Sample in 0.5 m depth, size 180 µm (b). Sample in 0.5 m depth, size 250 µm (c). Sample in 0.5 m depth, size 500 µm (d). Sample ini 1 m depth, size 180 µm (e). Sample in 1 m depth, size 250 µm (f). Sample in 1 m depth, size 500 µm (g). Sample in 1.5 m depth, size 180 µm (h). Sample in 1.5 m depth, size 250 µm (i). Sample in 1.5 m depth, size 500 µm

Table 2. Microplastic Polymers Based on FT-IR Results

Sample	Polymers found
0.5 m depth, size 180 - 250 µm	Polyethylenimine
	Poly (1, 1-dimethyl-3, 5-dimethylene piperidinium chloride)
0.5 m depth, size 250 – 500 µm	Poly (ethylene terephthalate)
	Poly (1, 4-butylene terephthalate)
	Polyester
0.5 m depth, size >500 µm	Polyethylenimine
1 m depth, size 180 – 250 µm	Polyethylenimine
	Poly (1, 1-dimethyl-3, 5-dimethylene piperidinium chloride)
1 m depth, size 250 – 500 µm	Poly (ethylene terephthalate)
	Poly (1, 4-butylene terephthalate)
	Polyester
1 m depth, size >500 µm	Polyethylenimine
	Poly (1, 1-dimethyl-3, 5-dimethylene piperidinium chloride)
1.5 m depth, size 180 – 250 µm	-
1.5 m depth, size 250 – 500 µm	Polyethylenimine
	Poly (1, 1-dimethyl-3, 5-dimethylene piperidinium chloride)
	Poly (ethylene terephthalate)
	Poly (oxalylhydrazide: terephthaloylhydrazide)
1.5 m depth, size >500 µm	Poly (ethylene terephthalate)
	Poly (1, 4-butylene terephthalate)
	Poly (oxalylhydrazide: terephthaloylhydrazide)
	Polyester

Reff : HR Aldrich FT-IR Collection Edition II, HR Hummel Polymer and Additives.

Table 2 shows that the types of polymers in The Mahakam River water samples include Polyethyleneimine, Poly (1, 1-dimethyl-3, 5-dimethylene piperidinium chloride), Poly (ethylene terephthalate), Poly (1, 4-butylene terephthalate), Polyester tere-& isophthalic acid, Polyester terephthalic acid, and Poly (oxalyl hydrazide: terephthaloyl hydrazide). Meanwhile, the samples from a depth of 1.5 meters and filtered using a 180 µm nylon sieve (Data sampling 1) were observed not to have microplastic polymers. This is associated with the lack of additional H_2O_2 doses while removing organic substances, which indicated the absence of non-plastic materials identified as microplastics.

The fastest-growing Poly (ethylene terephthalate) PET plastic is generally used for food packaging due to its safety, lightweight, hardness, toughness, and resistance to grease, oil, and heat, making it useful as a gas and moisture barrier. However, PET is non-biodegradable, susceptible to oxidation, and normally used to produce several domestic products such as beverage bottles, clothing and carpet fiber, medicine pots, rope, and others that can be recycled (Hossain et al., 2020). It is generally derived from processing crude oil derivatives such as terephthalic acid (TPA) and ethylene glycol (EG). It is often used as disposable bottles in the form of films but mainly as a fiber. However, PET has the potential to pollute the environment through its toxic antimony (Sb) content (Chu et al., 2021). Reduction of PET plastic can be carried out using a recycling process, which has been proven to provide benefits to the environment during manufacturing and end-of-life management (Rybaczewska-Blazejowska and Mena-Nieto, 2020). Another way is the degradation process by *Idonella sakaiensis* bacteria, which usually uses it as energy and carbon, thereby converting the plastic into a more environmentally friendly monomer (Yoshida et al., 2016).

Polymer plastic-type Poly (ethylene terephthalate) was found in the deeper water column at 1m and 1.5 m. This is in line with the findings of (Lenaker et al., 2019) that polymers with higher densities are often found in deeper sediments and columns. Meanwhile, polyethylene-type polymer, which is a low-density polymer, was found on the column surface, as also observed in research (Lestari et al., 2020). It is essential to recognize microplastic polymers because their characteristics, such as the structure, additives, and chemical composition, influence the degradation rates of microplastics. Environmental factors such as temperature and humidity, depositional matrices such as water, soil, sand, terrestrial versus aquatic, and depositional environment (Corcoran, 2021). Microplastic weathering significantly increases the adsorption of heavy metals by the PS polymer, changing the polymer's color and crumbling. Thus increasing the bioavailability of metal adsorption in the lower feeder (Seyfi, Katibeh and Heshami, 2021)

This research showed that microplastic contamination, specifically small-sized microplastics in the area close to the raw water intake, needs to be considered to improve the efficiency of WTP in removing microplastics. Some technologies, such as adsorption, membrane reactor filtration, and electrocoagulation, are some technologies with high efficiency (> 90%) in reducing microplastic contamination (Padervand et al., 2020) (Bodzek and Pohl, 2022). However, some of the microplastics, specifically the small ones, are still passed through to the final products despite the ability of WTP to reduce them. Meanwhile, conventional drinking water treatment plants' (WTP) performance in removing microplastic is still questionable.. Full-stage treatment in Conventional WTP consisted of intake, pre-sedimentation, coagulation-flocculation, sedimentation, sand filter, and disinfection units. Total microplastic removal efficiencies in WTP I and II were 66 and 62%, respectively. Microplastics with a size of 1–350 μm produced lower removal efficiency (33–53%) compared to the size of 351-<5,000 μm (53–76%). Based on the type of microplastic, the removal efficiency of fibers, fragments, and films was 61–65%; 86–100%; and 100% (Radityaningrum, Trihadiningrum and Soedjono, 2023). In conventional WTP in Thailand, the overall microplastic removal efficiency was found to be 67.6% and 57.2% in the dry and rainy seasons, with an average of 609.1 ± 84.7 p/L still present in the treated water (Kankanige and Babel, 2021). The microplastic content was significantly lower in treated water compared to raw water (river water). However, the concentration of MP in treated water was still relatively high (338 ± 76 to 628 ± 28 L−1), which was dominated by fragments and small-sized microplastics (<10mm) (Pivokonsky et al., 2018). Therefore, there is a need for further research in order to provide standard values of tolerance for microplastics allowed in treated water, monitor their level of contamination in raw water sources, and suggest better treatment methods. It is also vital for WTP to improve the capabilities of each unit or add new units to increase the efficiency of microplastic reduction.

There is also the need to implement efforts to prevent the sources of microplastic contamination in freshwater. This intervention in the upstream is required due to the capacity of rivers to act as the primary collector and distributor of microplastics into the marine environment. It is also essential to consider the human population density near water bodies and the waste management and wastewater disposal systems (Eerkes-Medrano, Thompson and Aldridge, 2015) (Rios Mendoza and Balcer, 2020). Meanwhile, WWTP is a wastewater treatment facility that treats wastewater from different sources to reduce the potential for microplastic contamination in rivers (Rios Mendoza and Balcer, 2020) (Bayo, Olmos and López-Castellanos, 2020). Samarinda City was observed to need to be equipped with an integrated WWTP. Optimally, efforts are being made to monitor and manage plastic waste at its sources. This effort requires the involvement of various parties, such as the government, the community, and researchers, to prevent the entry of plastic waste into the environment and find alternatives to plastic that are environmentally friendly (Hossain et al., 2020). Further research is needed to identify and map the distribution of microplastics and carry out mitigation. It is an effort to reduce microplastic degradation and fragmentation from various sources before more significant environmental impacts occur (Liu et al., 2020)

5. CONCLUSIONS

The research uncovered microplastics in all tested samples, with the highest concentration found in particles ranging from 180 µm ≤ - < 250 µm. The average density in the river's surface column was 25.4 particles per liter. Notably, the abundance of microplastics decreased as the depth of the river increased. This suggests a need to remove small microplastics from the river to enhance the efficiency of water treatment processes. The Fourier-transform infrared spectroscopy (FTIR) analysis identified the types of microplastics present in the samples, including: polyethyleneimine, poly (1, 1-dimethyl-3, 5-dimethylene piperidinium chloride), poly (ethylene terephthalate), poly (ethylene terephthalate), poly (1, 4-butylene terephthalate), polyester, polyester terephthalic acid, and poly (oxalyl hydrazide: terephthaloyl hydrazide). Further research is necessary to establish standard tolerance values for microplastics and to monitor contamination levels in both raw and treated water sources. The study also found that fibers were the predominant type of microplastic, followed by fragments and films. These microplastics primarily originate from domestic waste entering the waterbody through runoff, rain, wind, and flooding. It is crucial to map the distribution of microplastics, mitigate their occurrence, and reduce their degradation and fragmentation to minimize environmental impact. Further research and regulation are needed to provide standard tolerance values for microplastics allowed in treated water, monitor their contamination levels in raw water sources, and suggest better treatment methods. It is also important for conventional WTPs to improve the capacity of each unit or add high-efficiency technology units to increase the efficiency of microplastic reduction, such as adsorption, membrane reactor filtration, and electrocoagulation.

6. PATENTS

There are not patents resulting from the work reported in this manuscript.

Author Contributions: For research articles with multiple authors, include a brief paragraph outlining each author's contributions using the following format: "Conceptualization, Dwi Ermawati Rahayu. and Ika Meicahayanti; methodology, Dwi Ermawati Rahayu; validation, Searphin Nugroho and Fahrizal Adnan; formal analysis, Ratu Fortuna P,T Putri.; investigation, Ika Meicahayanti; resources, Ika Meicahayanti; data curation, Ratu Fortuna P,T Putri; writing—original draft preparation, Dwi Ermawati Rahayu; writing—review and editing, Ika Meicahayanti; visualization, Ratu Fortuna P,T Putri; supervision, Searphin Nugroho; project administration, Fahrizal Adnan. All authors have read and agreed to the published version of the manuscript." Authorship should be restricted to individuals who have made significant contributions to the research.

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REFERENCES

1. Akdogan, Z. and Guven, B., 2019. Microplastics in the environment: A critical review of current

understanding and identification of future research needs. *Environmental Pollution*, 254. https://doi.org/10.1016/j.envpol.2019.113011.

2. Alam, F.C. and Rachmawati, M., 2020. Development of Microplastic Research in Indonesia. *Jurnal Presipitasi : Media Komunikasi dan Pengembangan Teknik Lingkungan*, 17(3), pp.344–352. https://doi.org/10.14710/presipitasi.v17i3.344-352.
3. Alam, F.C., Sembiring, E., Muntalif, B.S. and Suendo, V., 2019a. Microplastic distribution in surface water and sediment river around slum and industrial area (case study: Ciwalengke River, Majalaya district, Indonesia). *Chemosphere*, [online] 224, pp.637–645. https://doi.org/10.1016/j.chemosphere.2019.02.188.
4. Alam, F.C., Sembiring, E., Muntalif, B.S. and Suendo, V., 2019b. Microplastic distribution in surface water and sediment river around slum and industrial area (case study: Ciwalengke River, Majalaya district, Indonesia). *Chemosphere*, [online] 224, pp.637–645. https://doi.org/10.1016/j.chemosphere.2019.02.188.
5. Ayuningtyas, W.C., 2019. Kelimpahan Mikroplastik Pada Perairan Di Banyuurip, Gresik, Jawa Timur. *Journal of Fisheries and Marine Research*, 3(1), pp.41–45. https://doi.org/10.21776/ub.jfmr.2019.003.01.5.
6. Azizah, P., Ridlo, A. and Suryono, C.A., 2020. Mikroplastik pada Sedimen di Pantai Kartini Kabupaten Jepara Jawa Tengah. *Journal of Marine Research*, 9(3), pp.326–332. https://doi.org/10.14710/jmr.v9i3.28197.
7. Badan Pusat Statisik, 2014. *Badan Pusat Statistik Provinsi Kalimantan Timur., 2014, Tabel Nama dan Panjang Sungai Menurut Kabupaten dan Kota Tahun 2014*. kaltim.bps.go.id.
8. Bahri, A.R.S., Ikhtiar, M., Baharuddin, A. and Abbas, H.H., 2020. Identification of Microplastic in Tilapia Fish (Oreochromis mossambicus) at Tallo River in Macassart. *International Journal of Science and Healthcare Research*, [online] 5(3), pp.406–411. https://doi.org/10.13140/RG.2.2.15592.90889.
9. Bayo, J., Olmos, S. and López-Castellanos, J., 2020. Removal of Microplastics from Wastewater. *Handbook of Microplastics in the Environment*, pp.1–20. https://doi.org/10.1007/978-3-030-10618-8_33-1.
10. Bellasi, A., Binda, G., Pozzi, A., Galafassi, S., Volta, P. and Bettinetti, R., 2020. Microplastic Contamination in Freshwater Environments : A Review , Focusing on Interactions with Sediments and Benthic Organisms. *Environment*, 7(30), pp.1–28.
11. Bodzek, M. and Pohl, A., 2022. Removal of Microplastics in Unit Processes Used in Water and Wastewater Treatment : a Review. *Arch*, 48(4), pp.102–128. https://doi.org/10.24425/aep.2022.143713.
12. BPS, 2019. *Jumlah Pelanggan PDAM Menurut Jenis Konsumen di Kota Samarinda, 2016-2018*. https://samarindakota.bps.go.id.
13. Chu, J., Hu, X., Kong, L., Wang, N., Zhang, S., He, M., Ouyang, W., Liu, X. and Lin, C., 2021. Dynamic flow and pollution of antimony from polyethylene terephthalate (PET) fibers in China. *Science of the Total Environment*, 771, pp.1–10. https://doi.org/10.1016/j.scitotenv.2020.144643.
14. Corcoran, P.L., 2021. Degradation of Microplastics in the Environment. In: T. Rocha-Santos and M.

Coasta, eds. *Handbook of Microplastics in the Environment*. Springer. pp.1–12. https://doi.org/10.1007/978-3-030-10618-8_10-1.

15. Dewi, M.K., 2016. the People of the Vicinity of the River Mahakam Kutai. *Jurnal Gerbang Etam*, 10(1), pp.75–83.
16. Dikareva, N. and Simon, K.S., 2019. Microplastic pollution in streams spanning an urbanisation gradient. *Environmental Pollution*, [online] 250, pp.292–299. https://doi.org/10.1016/j.envpol.2019.03.105.
17. Eamrat, R., Taweesan, A. and Pussayanavin, T., 2022. Assessment of Microplastics Distribution and Related Water Quality in an Urban Canal, Thailand. *Pollution*, 8(4), pp.1172–1184. https://doi.org/10.22059/POLL.2022.340679.1407.
18. Eerkes-Medrano, D., Thompson, R.C. and Aldridge, D.C., 2015. Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritisation of research needs. *Water Research*, 75(October), pp.63–82. https://doi.org/10.1016/j.watres.2015.02.012.
19. Ferraz, M., Bauer, A.L., Valiati, V.H. and Schulz, U.H., 2020. Microplastic concentrations in raw and drinking water in the sinos river, southern brazil. *Water*, 12(11), pp.1–10. https://doi.org/10.3390/w12113115.
20. Firdaus, M., Trihadiningrum, Y. and Lestari, P., 2020. Microplastic pollution in the sediment of Jagir Estuary , Surabaya City , Indonesia. *Marine Pollution Bulletin*, [online] 150(110790), pp.1–9. https://doi.org/10.1016/j.marpolbul.2019.110790.
21. Hanif, K.H., Suprijanto, J. and Pratikto, I., 2021. Identifikasi Mikroplastik di Muara Sungai Kendal, Kabupaten Kendal. *Journal of Marine Research*, 10(1), pp.1–6. https://doi.org/10.14710/jmr.v9i2.26832.
22. Harpah, N., Suryati, I., Leonardo, R., Risky, A., Ageng, P. and Addauwiyah, R., 2020. Analisa Jenis, Bentuk Dan Kelimpahan Mikroplastik Di Sungai Sei Sikambing Medan. *Jurnal Sains dan Teknologi*, 20(2), pp.108–115. https://doi.org/10.36275/stsp.v20i2.270.
23. Horton, A.A., Walton, A., Spurgeon, D.J., Lahive, E. and Svendsen, C., 2017. Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of the Total Environment*, [online] 586, pp.127–141. https://doi.org/10.1016/j.scitotenv.2017.01.190.
24. Hossain, S., Rahman, M.A., Ahmed Chowdhury, M. and Kumar Mohonta, S., 2020. Plastic pollution in Bangladesh: A review on current status emphasizing the impacts on environment and public health. *Environmental Engineering Research*, 26(6), pp.200535–0. https://doi.org/10.4491/eer.2020.535.
25. Kaliszewicz, A., Winczek, M., Karaban, K., Kurzydłowski, D., Górska, M., Koselak, W. and Romanowski, J., 2020. The contamination of inland waters by microplastic fibres under different anthropogenic pressure: Preliminary study in Central Europe (Poland). *Waste Management and Research*, 38(11), pp.1231–1238. https://doi.org/10.1177/0734242X20938448.
26. Kankanige, D. and Babel, S., 2021. conventional water treatment plant (WTP) in Thailand. *Journal of Water Process Engineering*, [online] 40(l), pp.1–9. https://doi.org/10.1016/j.jwpe.2020.101765.
27. Kapo, F.A., Toruan, L.N.L. and Paulus, C.A., 2020. Jenis dan Kelimpahan Mikroplastik pada Kolom Permukaan Air di Perairan Teluk Kupang. *Jurnal Bahari Papadak*, 1(1), pp.10–21.

28. Kemen L.H dan Kehutanan, 2021. *Status Sungai Mahakam*. [online] Kementrian Lingkungan Hidup dan Kehutanan, Ditjen Pengendalian Pencemaran dan Kerusakan lingkungan, Direktorat Pengendalian Pencemaran Air. Available at: <https://ppkl.menlhk.go.id/onlimo-2018> [Accessed 4 March 2022].
29. Klein, S., Dimzon, I.K., Eubeler, J. and Knepper, T.P., 2018. Analysis, Occurrence, and Degradation of Microplastics in the Aqueous Environment. In: M. Wagner and S. Lambert, eds. *Freshwater Microplastics*

merging Environmental Contaminants? Springer Open. pp.1–309. https://doi.org/10.1007/978-3-319-61615-5_3.

30. Kumar, R., Sharma, P., Manna, C. and Jain, M., 2021. Abundance , interaction , ingestion , ecological concerns , and mitigation policies of microplastic pollution in riverine ecosystem : A review Science of the Total Environment Abundance , interaction , ingestion , ecological concerns , and mitigation poli. *Science of the Total Environment*, 782(146695), pp.1–27. https://doi.org/10.1016/j.scitotenv.2021.146695.
31. Łabuz, T.A., 2021. Litter sources on the polish baltic shore – effect of increased anthropogenic pollution. *Studia Quaternaria*, 38(2), pp.85–100. https://doi.org/10.24425/sq.2021.136825.
32. Lambert, S., Boxall, A. and Sinclair, C.J., 2014. Occuuence, Degradation, and Effect of Polymer-Based Materials in the Environment. In: D.M. Whitacre, ed. *Reviews of Environmental Contamination and Toxicology*, 1st ed. Springer International Publishing. pp.1–53. https://doi.org/10.1007/978-3-319-01327-5.
33. Lechthaler, S., Waldschläger, K., Sandhani, C.G., Sannasiraj, S.A., Sundar, V., Schwarzbauer, J. and Schüttrumpf, H., 2021. Baseline study on microplastics in indian rivers under different anthropogenic influences. *Water (Switzerland)*, 13(12), pp.1–13. https://doi.org/10.3390/w13121648.
34. Lenaker, P.L., Baldwin, A.K., Corsi, S.R., Mason, S.A., Reneau, P.C. and Scott, J.W., 2019. Vertical Distribution of Microplastics in the Water Column and Surficial Sediment from the Milwaukee River Basin to Lake Michigan. *Environmental Science and Technology*, 53(21), pp.12227–12237. https://doi.org/10.1021/acs.est.9b03850.
35. Lestari, P., Trihadiningrum, Y., Wijaya, B.A., Yunus, K.A. and Firdaus, M., 2020. Distribution of Microplastics in Surabaya River, Indonesia. *Science of the Total Environment*, 726(138560), pp.1–9. https://doi.org/10.1016/j.scitotenv.2020.138560.
36. Liu, P., Zhan, X., Wu, X., Li, J., Wang, H. and Gao, S., 2020. Effect of weathering on environmental behavior of microplastics: Properties, sorption and potential risks. *Chemosphere*, 242(125193), pp.1–12. https://doi.org/10.1016/j.chemosphere.2019.125193.
37. Malla-Pradhan, R., Pradhan, B.L., Phoungthong, K. and Joshi, T.P., 2023. Microplastic in Freshwater Environment: A Review on Techniques and Abundance for Microplastic Detection in Lake Water. *Trends in Sciences*, 20(8), pp.1–15. https://doi.org/10.48048/tis.2023.5202.
38. McCormick, A.R., Hoellein, T.J., London, M.G., Hittie, J., Scott, J.W. and Kelly, J.J., 2016. Microplastic in surface waters of urban rivers: Concentration, sources, and associated bacterial assemblages. *Ecosphere*, 7(11), pp.1–22. https://doi.org/10.1002/ecs2.1556.

39. Napper, I.E., Baroth, A., Barrett, A.C., Bhola, S., Chowdhury, G.W., Davies, B.F.R., Duncan, E.M., Kumar, S., Nelms, S.E., Niloy, N.H., Nishat, B., Maddalene, T., Smith, N., Thompson, R.C. and Koldewey, H., 2023. TEMPORARY REMOVAL: The distribution and characterisation of microplastics in air, surface water and sediment within a major river system. *Science of The Total Environment*, [online] 901(August), p.166640. https://doi.org/10.1016/j.scitotenv.2023.166640.
40. Nizzetto, L., Bussi, G., Futter, M.N., Butterfield, D. and Whitehead, P.G., 2016. A theoretical assessment of microplastic transport in river catchments and their retention by soils and river sediments. *Environmental Science: Processes and Impacts*, 18(8), pp.1050–1059. https://doi.org/10.1039/c6em00206d.
41. NOAA, 2015. *Laboratory Methods for the Analysis of Microplastics in the Marine Environment: Recommendations for quantifying synthetic particles in waters and sediments*. [online] NOAA Marine Debris Division. Available at: <https://repository.library.noaa.gov/view/noaa/10296/noaa_10296_DS1.pdf>.
42. Noor, I.Y., Basuni, S., Kartono, A.P. and Kreb, D., 2013. Kelimpahan dan Sebaran Populasi Pesut Mahakam Kalimantan Timur. *Jurnal Penelitian Hutan dan Konservasi Alam*, 10(03), pp.283–296.
43. Nurwahyunani, A. and Rakhmawati, R., 2022. Kelimpahan Mikroplastik Pada Organ Pencernaan Ikan Mujair (Oreochromis mossambicus) di Waduk Malahayu Kabupaten Brebes. *Jurnal Ilmiah Multi Sciences*, 14(1), pp.18–22.
44. Padervand, M., Lichtfouse, E., Robert, D. and Wang, C., 2020. Removal of microplastics from the environment . A review. *Environmental Chemistry Letters*, [online] 18(3), pp.807–828. https://doi.org/10.1007/s10311-020-00983-1.
45. Pico, Y., Alfarhan, A. and Barcelo, D., 2019. Nano- and microplastic analysis: Focus on their occurrence in freshwater ecosystems and remediation technologies. *TrAC - Trends in Analytical Chemistry*, [online] 113, pp.409–425. https://doi.org/10.1016/j.trac.2018.08.022.
46. Piskuła, P. and Astel, A.M., 2022. Microplastics Occurrence in Two Mountainous Rivers in the Lowland Area—A Case Study of the Central Pomeranian Region, Poland. *Microplastics*, 1(1), pp.167–186. https://doi.org/10.3390/microplastics1010011.
47. Pivokonsky, M., Cermakova, L., Novotna, K., Peer, P., Cajthaml, T. and Janda, V., 2018. Occurrence of microplastics in raw and treated drinking water. *Science of the Total Environment*, [online] 643, pp.1644–1651. https://doi.org/10.1016/j.scitotenv.2018.08.102.
48. Pramaningsih, V., Suprayogi, S. and Setyawan Purnama, I.L., 2017. Kajian Persebaran Spasial Kualitas Air Sungai Karang Mumus, Samarinda, Kalimantan Timur. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan*, 7(3), pp.211–218. https://doi.org/10.29244/jpsl.7.3.211-218.
49. Radityaningrum, A.D., Trihadiningrum, Y. and Soedjono, E.S., 2023. Performance of Conventional Drinking Water Treatment Plants in Removing Microplastics in East Java, Indonesia. *Journal of Ecological Engineering*, 24(6), pp.129–143. https://doi.org/10.12911/22998993/162785.
50. Rios Mendoza, L.M. and Balcer, M., 2020. Microplastics in Freshwater Environments. In: T. Rocha-Santos, M. Costa and C. Mouneyrac, eds. *Handbook of Microplastics in The Environment*, 1st ed.

Switzerland: Springer Nature. pp.325–353. https://doi.org/10.1016/b978-0-12-409548-9.12394-2.

51. Rodrigues, M.O., Abrantes, N., Gonçalves, F.J.M., Nogueira, H., Marques, J.C. and Gonçalves, A.M.M., 2018. Spatial and temporal distribution of microplastics in water and sediments of a freshwater system (Antuã River, Portugal). *Science of the Total Environment*, [online] 633, pp.1549–1559. https://doi.org/10.1016/j.scitotenv.2018.03.233.
52. Rogowska, W., Skorbiłowicz, E., Skorbiłowicz, M. and Trybułowski, Ł., 2021. Microplastics in coastal sediments of eŁckie lake (Poland). *Studia Quaternaria*, 38(2), pp.109–116. https://doi.org/10.24425/sq.2021.136827.
53. Rybaczewska-Blazejowska, M. and Mena-Nieto, A., 2020. Circular economy: Comparative life cycle assessment of fossil polyethylene terephthalate (PET) and its recycled and bio-based counterparts. *Management and Production Engineering Review*, 11(4), pp.121–128. https://doi.org/10.24425/mper.2020.136126.
54. Sari, G., Kasasiah, A., Rahmawati Utami, M. and Trihadiningrum, Y., 2021. Microplastics Contamination in the Aquatic Environment of Indonesia: A Comprehensive Review. *Journal of Ecological Engineering*, 22(10), pp.127–140. https://doi.org/10.12911/22998993/142118.
55. Scherer, C., Weber, A., Stock, F., Vurusic, S., Egerci, H., Kochleus, C., Arendt, N., Foeldi, C., Dierkes, G., Wagner, M., Brennholt, N. and Reifferscheid, G., 2020. Comparative assessment of microplastics in water and sediment of a large European river. *Science of the Total Environment*, [online] 738(139866), pp.1–11. https://doi.org/10.1016/j.scitotenv.2020.139866.
56. Sembiring, E., Fareza, A.A., Suendo, V. and Reza, M., 2020. The Presence of Microplastics in Water, Sediment, and Milkfish (Chanos chanos) at the Downstream Area of Citarum River, Indonesia. *Water, Air, and Soil Pollution*, 231(355), pp.1–14. https://doi.org/10.1007/s11270-020-04710-y.
57. Seyfi, S., Katibeh, H. and Heshami, M., 2021. Investigation of the process of adsorption of heavy metals in coastal sands containing micro-plastics , with special attention to the effect of aging process and bacterial spread in micro-plastics. *Archives of Environmental Protection*, 47(3), pp.50–59. https://doi.org/10.24425/aep.2021.138463.
58. Sharma, R., 2019. *Experimental analysis of microplastics in beach sediment samples by density separation and microscopic examination*. ARCADA University of Applied Science.
59. Shen, M., Song, B., Zhu, Y., Zeng, G., Zhang, Y., Yang, Y., Wen, X., Chen, M. and Yi, H., 2020. Chemosphere Removal of microplastics via drinking water treatment : Current knowledge and future directions. *Chemosphere*, [online] 251, pp.1–13. https://doi.org/10.1016/j.chemosphere.2020.126612.
60. Shim, W.J., Hong, H. and Eo, S., 2017. Analytical Methods Identi fi cation methods in microplastic analysis : *Aanalytical methods*, 9, pp.1384–1391. https://doi.org/10.1039/C6AY02558G.
61. Standar nasional Indonesia, 2004. *SNI 03-7016-2004, Tata Cara Pengambilan Contoh Dalam Rangka Pemantauan Kualitas Air pada Suatu Daerah Pengaliran Sungai*.
62. Susanto, D.R. and Kiswantoro, A., 2020. Strategi Pengelolaan Wisata Susur Sungai Mahakam Berbasis Ekowisata di Samarinda. *Journal of Tourism and Economic*, 3(1), pp.1–10.
63. Sutanhaji, A.T., Rahadi, B. and Firdausi, N.T., 2021. Analisis Kelimpahan Mikroplastik Pada Air

Permukaan di Sungai Metro, Malang. *Jurnal Sumberdaya Alam dan Lingkungan*, 8(2), pp.74–84. https://doi.org/10.21776/ub.jsal.2021.008.02.3.

64. Tambunan, E., 2014. Dampak degradasi lingkungan terhadap transportasi sungai mahakam. In: *The 17th FSTPT International Symposium*. pp.22–24.
65. Tuhumury, N. and Pellaupessy, H.S., 2021. Identifikasi Keberadaan Mikroplastik Pada Caranx sexfasciatus Yang Dibudidayakan Di Perairan Teluk Ambon Dalam. *Jurnal Sumberdaya Akuatik Indopasifik*, 5(1), p.47. https://doi.org/10.46252/jsai-fpik-unipa.2021.vol.5.no.1.117.
66. Wagner, M. and Lambert, S., 2018. Microplastics are Contaminants of emerging Concern in Freshwater Environments: An Overview. In: M. Wagner and S. Lambert, eds. *Freshwater Microplastics Emerging Environmental Contaminants?* Springer Open. pp.1–309.
67. Wagner, M., Scherer, C., Alvarez-muñoz, D., Brennholt, N., Bourrain, X., Buchinger, S., Fries, E., Grosbois, C., Klasmeier, J., Marti, T., Rodriguez-mozaz, S., Urbatzka, R., Vethaak, A.D., Winther-nielsen, M. and Reifferscheid, G., 2014. Microplastics in freshwater ecosystems : what we know and what we need to know. *Environmental Sciences Europe*, 26(12), pp.1–9.
68. Wijaya, B.A. and Trihadiningrum, Y., 2019. Meso- and microplastics pollution in Surabaya River on Driyorejo to Karang Pilang Segment (in Bahasa). *Jurnal Teknik ITS*, 8(2), pp.211–216.
69. Wong, J.K.H., Lee, K.K., Tang, K.H.D. and Yap, P.S., 2020. Microplastics in the freshwater and terrestrial environments: Prevalence, fates, impacts and sustainable solutions. *Science of the Total Environment*, 719(137512), pp.1–15. https://doi.org/10.1016/j.scitotenv.2020.137512.
70. Yona, D., Mahendra, B.A., Arif, M., Fuad, Z., Sartimbul, A., Hikmah, S. and Sari, J., 2022. Kelimpahan Mikroplastik Pada Insang Dan Saluran Pencernaan Ikan Lontok Ophiocara porocephala Valenciennes , 1837 (Chordata : Actinopterygii) di Ekosistem Mangrove Dubibir , Situbondo. *Jurnal Kalautan Tropis*, 25(1), pp.39–47.
71. Yoshida, S., Hiraga, K., Takehana, T., Taniguchi, I., Yamaji, H., Maeda, Y., Toyohara, K., Miyamoto, K., Kimura, Y. and Oda, K., 2016. A bacterium that degrades and assimilates poly(ethylene terephthalate). *Science*, 351(6278), pp.1196–1999.
72. Yudhantari, C.I.A.S., Hendrawan, I.G. and Puspitha, N.L.P.R., 2019. Kandungan Mikroplastik pada Saluran Pencernaan Ikan Lemuru Protolan (Sardinella Lemuru) Hasil Tangkapan di Selat Bali. *Journal of Marine Research and Technology*, 2(2), pp.47–51.