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Microplastic Contamination in Water and Sediment at Maninjau Lake, Indonesia

Noverita D. Takarina[1], Tri R. Soeprobowati[2], Puti S. Komala[3], Luki Subehi[4], Marta Wojewódka-Przybył[5], Anna I.S. Purwiyanto[6], and Yulianto Suteja[7]

[1]*Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok 16424, Indonesia*

[2] *School of Postgraduate Studies, Universitas Diponegoro, Semarang 50241, Indonesia*

[3]*Department of Environmental Engineering, Faculty of Engineering, Universitas Andalas, Padang 25175, Indonesia*

[4]*Research Center for Limnology, Indonesian Institute of Sciences, Cibinong 16911, Indonesia*

[5]*Institute of Geological Sciences, Polish Academy of Sciences, Research Center in Warsaw, Twarda 51/55, PL00818 Warsaw, Poland*

[6]*Marine Science Department, Faculty of Mathematics and Natural Science, Sriwijaya University, Palembang 30128, Indonesia*

[7]*Marine Science Department, Marine Science and Fisheries Faculty, Udayana University, Bali 80361, Indonesia*

Maninjau Lake in Agam Regency, West Sumatra Province, Indonesia, plays a significant role in the primary supply of water, hydroelectric energy plants, tourism, and floating net cage cultivation. This study aims to examine the quantity of microplastic contamination in surface water and sediment in Maninjau Lake at 10 various locations. The microplastics were quantified in terms of abundance and categorised by their shape, size, and polymer. The results showed that microplastics abundance at all locations in water and sediment varied from 65.63 to 195.31 particles/m^3 and 199.52 to 7000 particles/kg DW. Fibre, film, fragment, and granule-shaped microplastics were identified in the sediment and water samples. The size ranges of the microplastics found in all samples were 300, 300-500, 500-100, and >1000 µm. The amount of microplastic abundance among locations was not significantly different ($p>0.05$), but it varied in form and size ($p<0.05$) with fibre and <300µm particle size in surface water and sediment, which were higher than in others. The dominant polymer type on the surface water and sediments is polyvinyl chloride. Since Maninjau is one of the prioritised lakes in Indonesia, these findings can be useful and may contribute to contamination management, especially in terms of microplastics.

Keywords: debris; freshwater lake; floating net cage; litter

I. INTRODUCTION

Plastic waste is one of the main contributors to environmental pollution and problems for society [1]. Based on a previous study, Indonesia ranked second among countries with the highest amount of plastic waste that is not properly managed in the world, around 0.48 – 1.29 million tons/year [2]. Plastic in waters will be fragmented through the process of photodegradation, hydrolysis, mechanical degradation, oxidation, and biodegradation [3,4]. This disintegrated plastic (<5 mm in size) is categorised as microplastics [5], which is grouped into two, namely primary and secondary. The primary microplastics are tiny particles created for synthetic textile fibres or cleaning chemicals. Meanwhile, secondary microplastics are the outcomes of fragmentation or the breakdown of larger plastic items [6]. Microplastics that enter the waters can accumulate in water bodies and settle in sediments. The nature of microplastics that absorb toxic hydrophobic compounds from the environment [7] can cause physiological disturbances in aquatic biota. Microplastics with a large size particle and high

*Corresponding author's e-mail: noverita.dian@ui.ac.id

specific mass will settle in the sediment, while those with a low specific mass float on the surface [8]. The microplastic in lakes is considered because of the fate, effects and characteristics of microplastics in lakes. According to Pan *et al.* 2023 [9], microplastic contaminants can destroy and enrich pollutants. In lakes, microplastics are distributed vertically and have high concentrations in sediments. Microplastics can also inhibit photosynthesis, interfere with liver function and cause death in aquatic organisms. In addition, microplastic particles have the ability to bind to other toxic chemicals such as PBTs (persistent, bio accumulative and toxic substances) and POPs (persistent organic pollutants) [10,11]. High use of plastic without proper waste management will have a direct impact on decreasing the value of environmental functions, one of which is lake water. Prior to 2018, improving the quality of lake water was a super priority program because it released a lot of pollutants, including debris, fish feed residue, erosion from group C mineral mining activities, and detergents, into the lake [12]. Studies on microplastics, especially in Indonesian lakes, have been conducted by several researchers. Helfira *et al.* 2022 [13], reported that film-type microplastics were most commonly found in the waters of Lake Lubuk Siam Riau. Research in Lake Towuti reported that fragments were most commonly found in the waters [14]. The same results were also reported by Ramadan and Sembiring (2020) [15] that fragment-type microplastics were found in the waters of Jatiluhur reservoir. Fragment and foam-type microplastics are also dominantly found in the waters of Lake Singkarak. From these studies there has been no record of microplastics in sediments [12]. Maninjau Lake in Agam Regency, Padang, West Sumatra is a techno volcanic lake with a 99.5 km2 surface area and 105 m average depth. The lake is widely used by the local community as the primary source of water, hydroelectric energy, aquaculture, and tourism [16]. The higher use of the water, both in the lake and catchment area, will stimulate poor water quality (eutrophication and sedimentation) and biodiversity decrease. The lake can also be polluted through the increasing of floating net cages [17], land use changes within the catchment area, settlement growth in the lakeshore area, the conversion of rice fields into fishponds, infrastructural development, and anthropogenic activities. In the spatial plan for the National Strategic Area (KSN) of Lake Maninjau, fish farming activities with floating net cages at Maninjau Lake use aquaculture containers that are harmful to the environment. There was also an uncontrolled increase in floating net cages activities that exceeded the lake's capacity with 17,000 plots. These aquaculture activities are dependent on the continuous use of nets, ropes, and other fishing gear that are made from plastic [18]. Due to the increase in human activities at the lake, it is important to investigate microplastics as pollutants. Therefore, this study was carried out in July 2022 to investigate microplastic contamination of water and sediment at different locations in Maninjau Lake.

II. MATERIALS AND METHOD

A. Study Area

Water and sediment sampling were carried out in July 2022 at Maninjau Lake in West Sumatra. There were a total number of 10 sites to represent the west (4,5,6,7,8,9,10) and east (1,2,3) areas with 3 replicates. The sampling for microplastic in water was carried out from 10 sites (S1-S10), while that of sediment was conducted at 9 stations (S2-S10) (Figure 1) because site 1 was too deep. As shown in Figure 1, site 1 is the centre of the lake, site 2 is a place in front of the hotel, and site 3 is a station with floating net cages. Furthermore, site 4 is the outflow of the lake, namely the Batang Antokan River, 5 and 6 are areas near the settlement, 7 and 8 have no residential areas, while sites 9 and 10 are the floating net cage area.

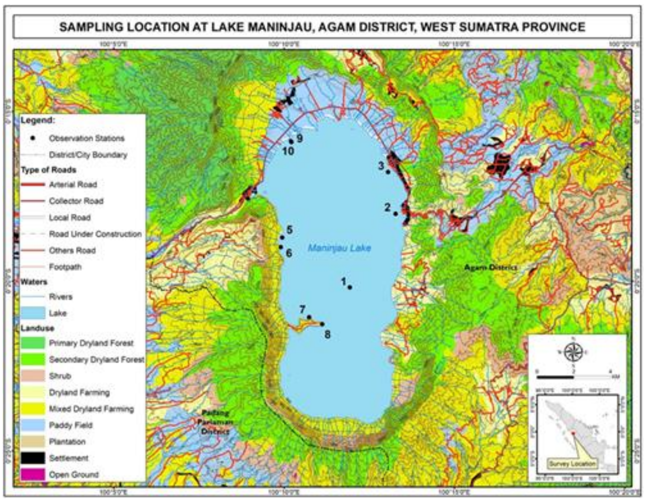

Figure 1. Geographic location of Maninjau Lake's study area and sampling sites.

A. Sampling Method

The sampling method in this study is based on a previous investigation by Takarina *et al.*, 2022 [19]; Suteja *et al.*, (2021b) [20]. The water and sediment sampling was carried out in 10 points on Maninjau Lake. Water samples were collected using a 16 cm diameter plankton net with a 300 µm mesh [21]. Plankton nets are placed on the vessel's side and pulled horizontally for approximately 15 minutes with speed of the boat was 0.06 knots and trawling distances ranged approximately 32 m [7], while the samples of sediments were taken with Ekman Grab after towing was completed. The collected samples are placed in HDPE bottles and put in an ice container during the field sampling [19].

1. Microplastic isolation

Water samples were isolated by filtering 1 L of water using a 5000 µm stainless-steel filter [22]. The filtered sample was placed in a glass beaker containing a saturated sodium chloride (NaCl) solution and stirred [19]. The sample was suspended in a NaCl solution to remove any leftover contaminants, reduce washing time, and maximise the density [23]. Generally, microplastic polymers have a density of more than 1 g/cm^3. Since NaCl compounds can make water samples denser, all microplastics will float to the top of the supernatant [24]. After stirring the solution, the sample's heavier components were drained. Subsequently, the surface of the supernatant was transferred into a measuring cup using a 20 mL pipette with 3 repetitions every 2 hours. The sediments were isolated by drying the 500 g wet samples at 60°C for 24 h to reduce the water content [25]. Microplastic analysis using the dry weight obtained from each sample ranged from 13-250.6 g. The dried sediments were grounded with a mortar and passed through a stainless-steel filter measuring 5000 µm. Approximately 13-250 grams of the samples were taken and suspended in a glass beaker containing a saturated NaCl solution [19]. Heavy material was drained from the sample after the solution had been stirred and the surface of the supernatant was transferred into a measuring cup using a 20 mL pipette with 3 repetitions every 4 hours. The solution of the surface water supernatant and sediment in the glass beaker of all repetitions was filtered using 0.45 µm Whatman Cellulose Nitrate paper, with a circle diameter of 47 mm, assisted by a vacuum pump with a pressure of 15 kPa. The filter paper was then kept in Petri dish for further observation (shape, size and polymer of microplastic).

2. Microplastic identification and analysis

Microplastic identification in surface water and sediment samples were categorised by shape, size, and polymer. The criteria of Cordova *et al.* (2019) [26] and Suteja *et al.* (2021b) [20] were used to determine the presence of microplastic particles, which include those with a smaller size of less than 5 mm, no cellular tissue, homogeneous colour, not segmented or branched. Furthermore, this study used criteria based on Horton *et al.* (2017) [27], where the particles that qualify as microplastics have at least two of these requirements, namely those with abnormal colour and homogeneous texture, unusually contrasting colour, unnatural shape, flexibility, the fibres strands that hold their shape when tweezed, glass, and glossy. Microplastic forms were categorised according to fibres, fragments, granules, and films [19], with sizes, ranging from <300, 300-500, 500-100, to >1000 µm [20]. An Olympus CX22 microscope with 10 x 4 or 10 x 10 magnification was used for identification based on shape and size. The polymers were also identified by Raman spectroscopy analysis using HORIBA - The LabRAM HR Evolution Raman Microscopes with a 785 nm laser beam and 600 g/mm grating. The polymers were analysed using representatives of the most predominant types of microplastic in each sample. Identification of polymers was carried out using a representative sample consisting of 9 sediment samples and 10 water samples. The type of polymer from the spectrum was subsequently determined using a former report by Cowger *et al.*, (2021) [28]. The obtained data from Raman analysis were inserted to OpenSpecy (software web). Baseline correction and smoothing was applied to the test spectra to increase the signal-to-noise ratio in each software. The software was then used to identify the spectra according to the standard matching method and the first of top ten matches were evaluated for a true positive match to the known identity of the spectra. The abundance of microplastics in surface water and sediment were reported as the number of microplastic particles per cubic meter (particles/m^3) and microplastic particles per kilogramme of dry weight sediment (particles/kg DW), respectively. Non-parametric tests were used in statistical analyses, specifically the Kruskal-Wallis test [29].

III. RESULT AND DISCUSSION

A. Microplastic Abundance in Surface Water and Sediment

Microplastics were found in all surface water samples and based on a non-parametric test, the total abundance at each site was not significantly different (p>0.05, Kruskal-Wallis). Moreover, microplastics may be transported and distributed differently depending on hydrodynamic factors such as river discharge, wind stress, and tidal pressures [30]. In water, microplastic abundance varied from 65.63 to 195.31 particles/m^3 (Table 1). The highest abundance was detected at site 2 (195.31 particles/m^3) was detected at site 2, followed by site 3 with a value of 128.13 particles/m^3. Both sites are located east of Maninjau Lake, specifically, site 2 is a place in front of the hotel, while site 3 is a station with floating net cages. Meanwhile, site 1, which is situated in the lake's centre, had 65.63 particles/m^3. This showed that microplastic abundance in surface water was greater and close to the land than in the lake's centre. There are various direct and indirect the source of microplastics into lakes, such as plastics from human activities that originate on land [31]. Plastics from anthropogenic activities, namely littering can easily enter the water unlawfully [31]. The abundance of microplastics found in this lake can be linked to fisheries activities. Based on Anagnosti *et al.* (2021) [32], the main source of microplastics will come from toiletries, cleaning, and medical products and industrial production processes. This material enters the waters through the discharge of domestic waste. However, this primary material is wasted during the waste management process. In contrast to this, Horton *et al.* 2017 [27] reported that fishing nets abandoned in lakes or rivers and abandoned plastic sheds can be the extensive source of microplastics. It was discovered that fishing nets and ropes are potential sources, which are commonly made from polypropylene or polyethylene polymers [33,34]. This is also indicated by a large amount of fibre in the water as shown in Figure 3, which is made up of fibre from furniture, textiles, ropes, fishing nets, and infiltration wastewater from household laundry [17,29,35,36]. The distance from the sample location to land operations is the cause of low abundance in site 1 [20]. Microplastics were found in all sample sediments from 9 sites at Maninjau Lake with abundance, which ranged from 199.52 to 7000 particles/kg DW (Table 1). The highest abundance of 7000 particles/kg DW was observed at site 6, which is an area with fish farming activities and dense residential areas [37]. Based on the results, the second-highest microplastic abundance of 4898.99 particles/kg DW was observed at site 5, which is close to site 6. Meanwhile, the lowest abundance, with a value of 199.52 particles/kg DW was discovered at site 9, which is far from residential areas. There was a higher microplastic abundance at site 6 than at other sites, but no significant difference between each site (p>0.05, Kruskal-Wallis). Mendes *et al.* (2021) [38] stated that the abundance can also be influenced by the texture and size of the particles. A fine sedimentary texture like clay has a greater potential for the adsorption of microplastic particles than a coarse sedimentary texture like sand [39]. This is in line with the result at sites 9 and 10, with larger particle sizes such as sand, which had a lower size compared to other sites with clay sediment texture. Microplastics in sediments were more abundant than in surface water. This is related to the density of microplastics that increases during the degradation process and can be caused by the incorporation of microplastics into phytoplankton aggregates, thereby allowing microplastics to sink to the bottom of the water [30].

Table 1. Microplastic in surface water and sediment of Maninjau Lake

St	Surface water		Sediment	
	Particle	Abundance (particles/m^3)	Particle	Abundace (particles/) kg DW
1	42	65.63	-	-
2	76	118.75	89	2688.82
3	125	195.31	45	2045.45
4	82	128.13	93	391.41
5	69	107.81	97	4898.99
6	44	68.75	91	7000.00
7	70	109.38	53	3441.56
8	78	121.88	53	2523.81
9	79	123.44	50	199.52
10	55	85.94	91	385.27
$\bar{x}$	72	112.5	73.56	2619.43

Table 2. Comparison microplastic abundance with other studies

Location	Microplastic Abundance		Reference
	Water (particle/m^3)	Sediment (particle/kg DW)	
Maninjau Lake, Indonesia	65.63-195.31	50-93	This study
West Dongting Lake, China	616.67–2216.67	320–480	[40]
South Dongting Lake, China	716.67–2316.67	200–1150	[40]
Poyang Lake, China	500-3400	54-506	[41]
Siombak Lake, Indonesia	93-519	521-1481	[42]
Songshan Lake, China	2.29	244	[43]

B. Microplastic Form/Shape

Among the forms of microplastic, namely fibre, fragment, film, and granules (Figure 2), the most frequent in surface water were fibres, followed by fragments, films, and granules with 63.4%, 27.8%, 6.2%, and 2.7%, respectively. Similarly, in sediment microplastic samples, fibres are more dominant compared to fragments, films, and granules, with values of 47.2%, 22.1%, 16.4%, and 14.3%, as shown in Figure 3. The Kruskal-Wallis tests indicated that the microplastic form was significantly different ($p<0.05$) among the sampling sites. On sites 3, 9, and 10 with the fishing activities, fibre showed the dominant percentage. The primary sources of microplastic fibres are a large number of materials in daily activities such as furniture, textiles, etc, and fragmentation including ropes, synthetic fabrics, floating net cages and fisheries activities, or infiltration wastewater from home laundries [17,29,35,36]. Fragments were the second dominant component across all forms accounting for MP particles. An area near the settlement, namely site 6 has the dominant type of microplastic fragments related to sources of household waste pollution such as bottles and plastic bags. Microplastic with the film form ranked third in water surfaces and sediment. The low percentage of microplastic film was due to transportation through the current. Therefore, some forms float on water because their low density can move to other places [44]. Microplastic granule has the lowest percentage of particles, which can be caused by organisms that are easier to remove compared to fibre [45].

Based on the identification of all microplastic particles, the dominant form in surface water and sediment was fibre as shown in Figure 3. The elongated, fibre-like form indicated a greater potential for entanglement in the gills or digestive tract of organisms. The most frequent microplastic forms of fibre in surface water and sediment can be a further study related to their toxicity for microplastic pollution risk assessments in aquatic ecosystems, especially for the health of the aquatic organisms in Maninjau Lake [46].

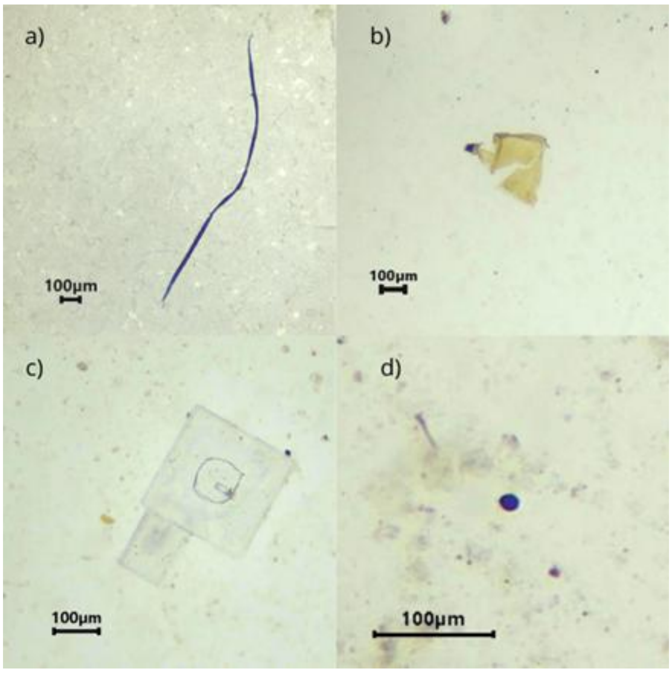

Figure 2. Microplastic forms from selected particles. (a) fibre, (b) fragment, (c) film, (d) granule

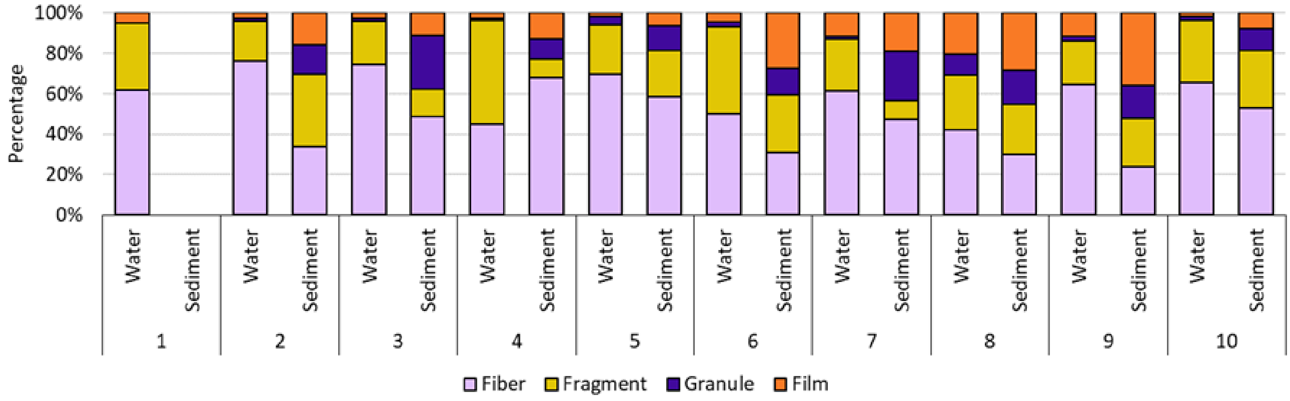

Figure 3. Distribution of microplastic forms in each site surface water and sediment

C. Microplastic Size

Based on size, microplastics were divided into <300, 300-500, 500-100, and >1000 μm. Microplastics in surface water were dominated by sizes of <300 μm (45.83%), followed by 500-100μm (22.92%), >1000μm (16.94%), and 300-500μm (14.31%). Meanwhile, the size of sediment was also dominated by sizes of <300μm (61.03%), followed by >1000μm (16.16%), 300-500μm (12.84%), and the lowest percentage size was 500-1000μm (9.97%) as shown in Figure 4. Fragments and granules that dominate microplastics were <300 μm, while fibres predominate in those > 1000 μm. According to the Kruskal-Wallis test, microplastic size was significantly different ($p<0.05$) at each site in surface water and sediment, where approximately the same percentage was identified at site 1. Microplastics measuring <300μm were the most dominant at sites 2 and 3, while there were no sizes >1000μm at those sites. It was also discovered that size <300 μm was dominant in water and sediment at each site.

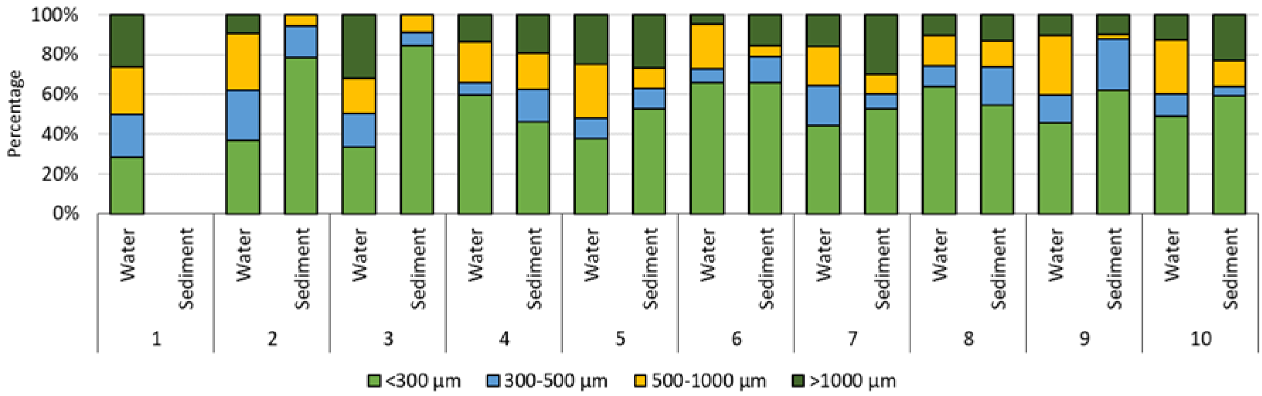

Figure 4. Distribution of microplastic sizes in each site surface water and sediment

D. Microplastic Polymer Type

A total of 12 polymer types were identified from selected microplastic particles in surface water and sediment, including polyvinyl alcohol (PVA), polysulfone (PSU), polyvinyl chloride (PVC), phenoxy resin, polystyrene (PS), nylon 6(3), poly(phenylene sulfide) (PPS), polypropylene (PP), polyphenylsulfone (PPSU), polyvinyl formal (PVF), poly(ethylene glycol) (PEG), and high-density polyethylene (HDPE) (Table 3). Raman spectra of selected particles were confirmed with an Open Specy database as presented in Figure 5. The percentage of polymer type to the total microplastic found in selected microplastic from surface water and sediment are stated as follows PVC (20.00%) > PSU (13.33%) > PVA (6.67%) > phenoxy resin (6.67%) > PS (6.67%) > Nylon 6(3) (6.67%) > PPS (6.67%) > PP (6.67%) > PPSU (6.67%) > PVF (6.67%) > PEG (6.67%) > HDPE (6.67%) (Figure 6). Among all sites and mediums, namely surface water and sediment, high-density polymers (PVC) were more common than low-density polymers (PP).

Table 3. Polymer of microplastic in surface water and sediment from Maninjau Lake

	Surface water	**Sediment**
Type of polymer	PVA, PSU, PVC, Phenoxyresin, PS, PSU, Nylon6(3), Polyphenylene sulfide	PP, PPSU, PVF, PEG, PVC, HDPE

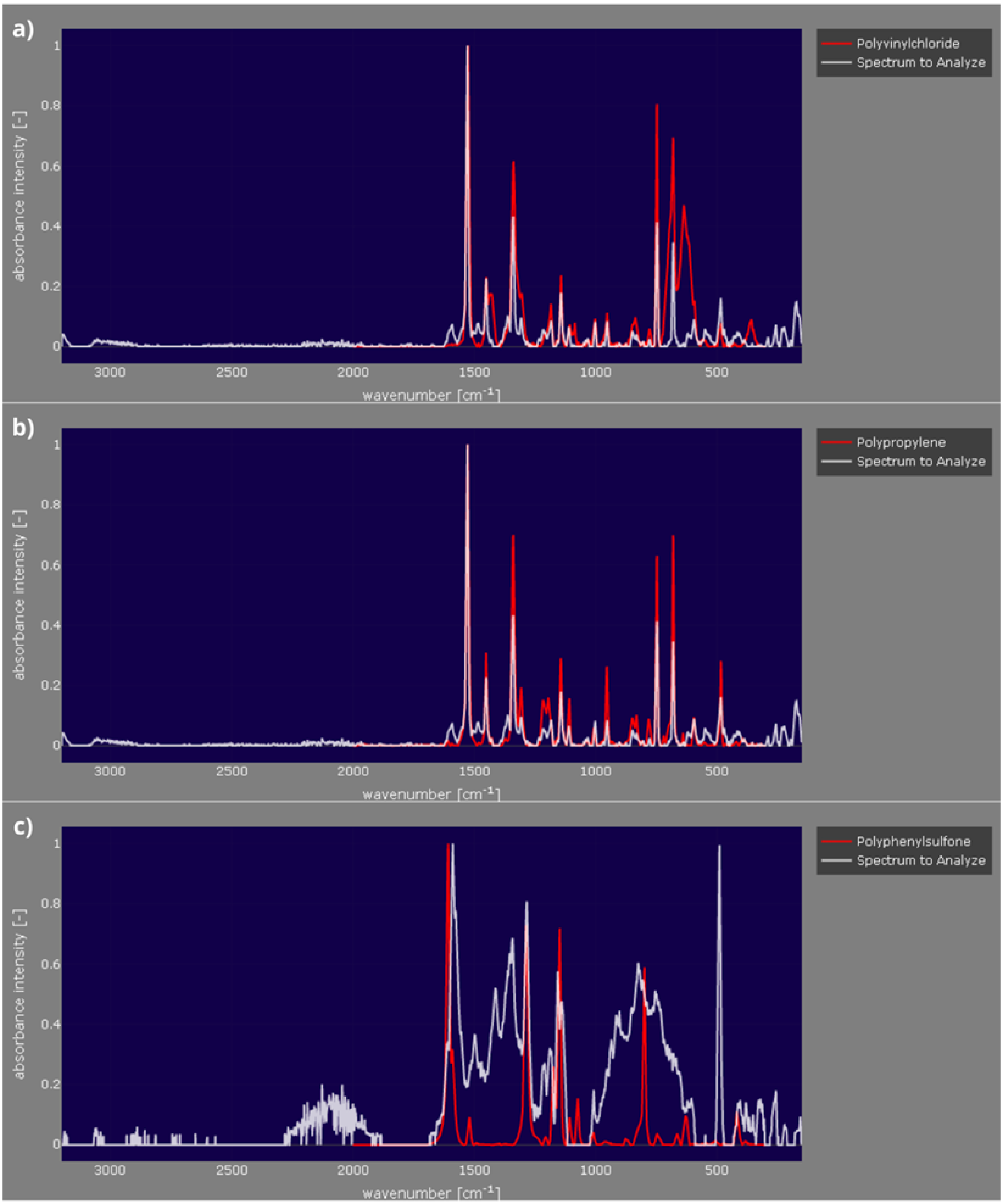

Figure 5. Raman spectra of (a) polyvinyl chloride, (b) polypropylene, (c) polyphenylsulfone

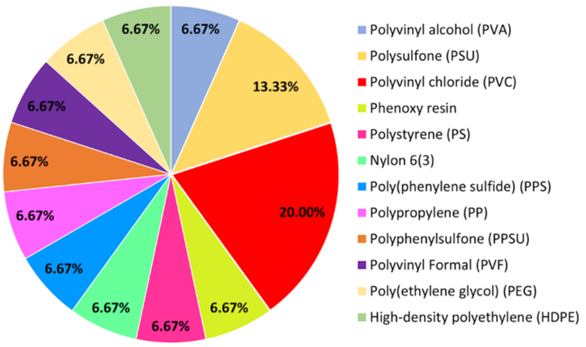

Figure 6. Composition of polymer types from selected microplastic in surface water and sediment.

IV. CONCLUSION

This study identified microplastics in surface water and sediments at all sites. Based on the results, microplastic abundance in water varied from 65.63 to 195.31 particles/m3 and ranged from 199.52 to 7000 particles/kg DW in sediments. The average abundance with a value of 2619.43 particles/kg DW in sediments was more compared to surface water, which was 112.5 particles/m3. Microplastics in water and sediment consist of fibres, fragments, granules, and films with fibre as the most dominant in both mediums and were dominated by sizes of <300 µm. The identified polymers are diverse, these include polyvinyl alcohol (PVA), polysulfone (PSU), polyvinyl chloride (PVC), phenoxy resin, polystyrene (PS), nylon 6(3), poly(phenylene sulfide) (PPS), polypropylene (PP), polyphenylsulfone (PPSU), polyvinyl formal (PVF), poly(ethylene glycol) (PEG), and high-density polyethylene (HDPE). Polyvinyl chloride (PVC) is more common than other polymers. This abundance value shows that Maninjau Lake has been polluted with microplastics in water and sediment. Microplastic contamination in the lake affected water quality and aquatic species. This showed that the role of the lake as the primary water source can be harmful to the population, therefore, it needs to be controlled from human activities as pollutant contributors. The finding of microplastics in the environment, both in surface water and in sediments, indicates that these contaminants have entered the lake's water system. With this in mind, research development can be directed at environmental management in reducing microplastics and investigating contamination of microplastics in biota. As it is known that microplastics can enter through the food chain. Analysis of microplastic polymers shows microplastic pollution based on the source so that efforts to mitigate microplastic pollution can be carried out in Indonesian lakes.

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