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Abundance and Characteristics of Microplastics in Surface Water of Lake Singkarak in Tanah Datar, West Sumatra, Indonesia

Deswati Deswati[1]✉ | Yulizar Yusuf[1] | Zaki Aiwa Putra[1] | Adewirli Putra[2]

1. Department of Chemistry, Faculty of Mathematics and Natural Science, Andalas University, P.O. Box 25163, Padang, Indonesia
2. Department of Medical Laboratory Technology, Syedza Saintika University, P.O. Box 25132, Padang, Indonesia

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ABSTRACT

The distribution of microplastics (MPs) in freshwater bodies is receiving increasing attention due to the discovery of MPs in lake organisms that can be consumed. The small size of MPs makes them tend to float in the water column, making it easy for them to enter and accumulate in lake organisms. However, research on MPs in freshwater areas is still lacking, and no studies have been conducted in Lake Singkarak. This study aims to analyze the abundance of microplastics in surface water samples from five sampling stations in Lake Singkarak. Visual analysis of MPs was conducted using a B-350 Optical Stereo Microscope, and polymer-type analysis of MPs was performed using Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR). The abundance of MP pollutants in surface water ranged from 117.5 to 202.5 particles L^{-1}. The characteristics of MP pollutants based on shape, color, and size were predominantly fragments (42.81%), black (47.94%), and ≤100 µm in size (53.67%). The polymer types identified were polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), and polyvinyl chloride (PVC). The results of this study are expected to provide valuable references for a better understanding of MP pollution in the surface water of Lake Singkarak.

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INTRODUCTION

Microplastics (MPs) are tiny plastic particles less than 5 millimeters in size. The presence of MPs in water is due to humans' high usage of plastics. Boucher and Friot (2017) categorize MPs into two types: primary and secondary MPs. Primary MPs are microscopic plastic particles produced in specific products, such as microbeads in beauty and personal care products and plastic pellets in industrial manufacturing. Secondary MPs are formed from the degradation of more oversized plastic products, such as plastic bottles, plastic bags, and fishing nets, through degradation processes triggered by UV light, mechanical abrasion, and other environmental conditions.

Costa and Barletta (2015) state that MPs have been found in water since the 1970s. Researchers pay special attention to MPs in water bodies because organisms like zooplankton quickly consume MPs (Cole et al., 2013), which are then transferred to higher trophic levels (Setälä et al., 2014). MPs exist in lake waters and spread across the surface water, water column, and sediments. On the surface, MPs float and are easily dispersed by wind and currents. In the water column, microplastics are dispersed, disturbing aquatic organisms at various levels. MPs

*Corresponding Author Email: *deswati@sci.unand.ac.id*

settle at the bottom of lakes, causing long-lasting sediment pollution in sediments.

Lakes serve as the primary disposal sites for MPs in freshwater ecosystems because plastic waste can accumulate and persist for extended periods (Deswati, Tetra, Hayati, et al., 2023). Additionally, lakes with high MP reserves can become significant sources of MP for downstream river basins. Microplastics enter lakes from four primary sources: domestic waste, such as cleaning products containing microbeads and synthetic fibers from clothing, contaminates water with microplastics as they are difficult to filter out during wastewater treatment. Industrial waste, including plastic fragments and small plastic pellets, also enters water bodies due to inadequate waste management. Agricultural runoff from degraded plastic mulch and plastic-contaminated organic fertilizers is carried by rainwater into lakes. Additionally, recreational activities, such as the use of plastic equipment, plastic debris from boats, and tire dust from vehicles, contribute to microplastic pollution in freshwater ecosystems. (Galafassi et al., 2019; Lusher et al., 2017). Domestic waste comes from household cleaning products, while industrial waste originates from factories disposing of plastic without adequate treatment (McCormick et al., 2014). Agricultural runoff is caused by using biosolid fertilizers or contaminated irrigation water (Frere et al., 2017). Recreational activities contribute MP from equipment and litter left by tourists. Studies show that MPs exist in various freshwater systems, such as rivers, lakes, and estuaries (Eerkes-Medrano et al., 2015).

The presence of MPs in lakes significantly impacts the environment, human health, and social and economic aspects. Microplastics affect aquatic animals, food chains, and water quality. Fish, plankton, and other organisms can ingest MPs, leading to digestive issues, malnutrition, and death (Wright et al., 2013). There is substantial evidence that aquatic organisms, such as fish (Sanchez et al., 2014), invertebrates (Hurley et al., 2017), and waterfowl (Holland et al., 2016), consume microplastics. Ingesting MPs causes adverse effects on aquatic organisms and humans through trophic transfer (Rochman et al., 2015). Microplastics also carry harmful chemicals that degrade water quality and enter the food chain, affecting top predators like birds and aquatic mammals (Suparno et al., 2024). Consuming water and food from lakes contaminated with MPs can lead to exposure to plastic particles and harmful chemicals, posing health risks (Rochman et al., 2015; Syamsu et al., 2024), such as digestive and respiratory issues. Social and economic impacts include losses in the fisheries and tourism sectors due to declining environmental quality and ecosystem health (Deswati et al., 2023a,b).

Several studies indicate that MP pollution occurs more frequently in marine ecosystems than in freshwater (Besseling et al., 2017; Wang et al., 2020). However, MP pollution in freshwater is also important to study because freshwater ecosystems often serve as accumulation points for plastics carried by rivers, eventually leading to the ocean. MP pollution in freshwater can affect water quality, the health of aquatic organisms, and the human food chain that depends on these water sources. Additionally, the nature and distribution of microplastics in freshwater differ from those in marine ecosystems due to variations in pollution sources and local environmental dynamics. Microplastic pollution has been found in lakes (Alfonso et al., 2020; González-Pleiter et al., 2020). Unfortunately, no studies on MP pollution in Lake Singkarak have been conducted. Research is needed to identify the sources of MP pollution, which could originate from industrial waste, household waste, or everyday plastic products. Identifying pollution sources allows for appropriate mitigation actions, such as reducing plastic use, increasing recycling, and protecting the environment (Ogonowski et al., 2018; Revel et al., 2018). This research also helps understand the distribution of MPs in the lake and its impact on the aquatic ecosystem, providing a reference for the community on the negative impacts of MPs on the environment, health, and socio-economics.

MATERIAL & METHODS

Description of the Study Location. In this study, surface water sampling was conducted at five stations (T1, T2, T3, T4, T5), namely: Malalo (0°38’20.0”S 100°31’16.4”E), Padang Laweh (0°35’31.6”S 100°29’43.9”E), Sumpur (0°32’34.6”S 100°29’07.7”E), Ombilin (0°33’32.6”S 100°32’54.4”E), and Simawang (0°36’09.0”S 100°34’19.4”E) (Figure 1).

Sample Collection. Water samples (20 L) were collected using sterile HDPE bottles at each station. These samples were filtered using a 3-inch diameter stainless steel filter with mesh sizes of 5 mm and 200 µm, then placed into sample bottles. Each sample was labeled to prevent mixing and stored in a cooler box to maintain its quality until it arrived at the laboratory for further analysis.

Contamination Prevention and Quality Control. In this study, all solutions used were filtered to prevent contamination by MP particles. Filtration was carried out using Whatman

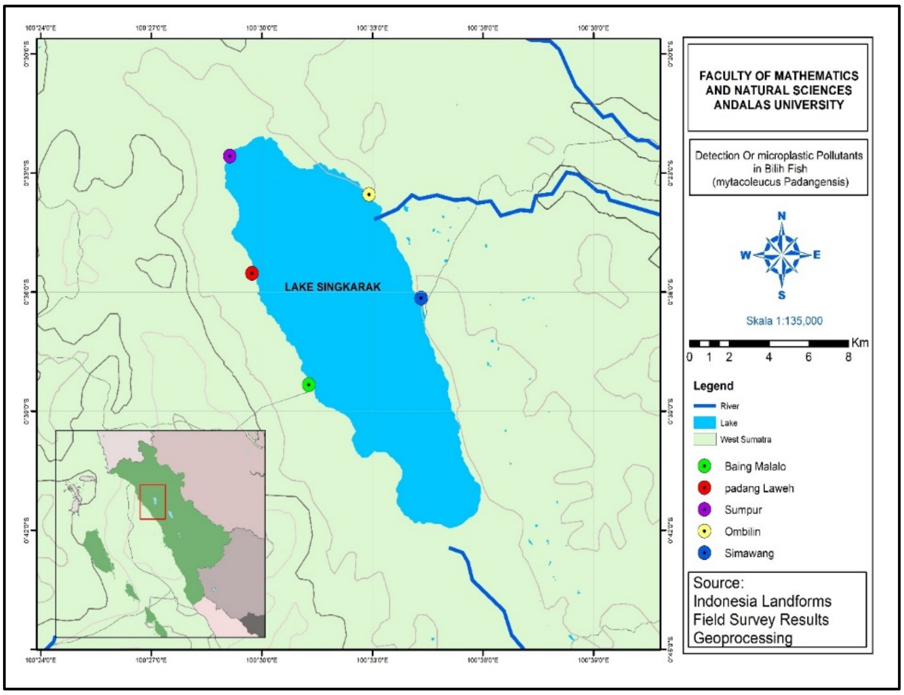

Fig. 1. Research sampling locations in Lake Singkarak, West Sumatera, Indonesia Source: Geospatial Agency of Special Region of Singkarak (2024)

Table 1. Sampling station descriptions

No	Stations	Description
1	Malalo	This station is a densely populated area, evident from the numerous residential settlements along the lake, leading to an accumulation of household waste in the water body.
2	Padang Laweh	This station is located near local agricultural irrigation areas (rice fields and gardens), which may contribute waste from agricultural activities.
3	Sumpur	This station is adjacent to natural tourist areas and accommodations (Tanjung Mutiara Beach and Sumpur Hotel), which may result in waste accumulation from tourist activities in the water body.
4	Ombilin	This station is located behind the Ombilin dock and bridge, which is the water exit gateway from the lake. Additionally, this location is close to a souvenir market, which may contribute waste from market activities.
5	Simawang	This station is situated far from human activities, with only a few mosques and restaurants in the vicinity. However, it is still possible that this location is exposed to microplastic pollutants.

Source: https://tanahdatarkab.bps.go.id/

No. 42 filter paper with a diameter of 90 mm and a pore size of 2.5 μm, doubly distilled water, as well as 30% H_2O_2 and 5 M NaCl solutions. The stereo microscope area was cleaned with alcohol to ensure no microplastic pollutants were present around the equipment. Additionally, gloves, masks, and cotton lab coats were worn during the procedures to prevent contamination.

Sample Extraction. The procedure for analyzing the abundance of MPs in surface water samples was adapted from previous studies (Masura et al., 2015). A 200 mL lake water sample was mixed with 20 mL of 30% H_2O_2 and homogenized using a magnetic stirrer for 5 minutes at 40°C with a stirring speed of 250 rpm. The sample was then covered with aluminum foil to avoid environmental contamination and left to stand for 24 hours. Afterward, the sample was filtered using Whatman No. 42 filter paper with a diameter of 90 mm and a pore size of 2.5 μm with the aid of a vacuum pump. The obtained filter paper was placed in a sterile petri dish and air-dried in a closed room.

Microscopic Examination. Dried microplastic pollutants on the filter paper were identified based on shape, color, and size under an Optical Stereo Microscope (Meiji B-350) equipped with a camera connected to a laptop, assisted by Motic Image Plus 3.0 software. Observations were made at 100x magnification. The number of MPs was determined by manually counting the particles displayed on the laptop screen. The particles observed had the following characteristics: particle size < 5 mm, homogeneous color, no cellular structure, and unsegmented and unbranched forms. Microplastic particles were categorized based on shape as fibers, beads, fragments, and foams, and based on size as <100 μm, 101–500 μm, 500–1000 μm, and >1000 μm (Cole et al., 2013; Hidalgo-Ruz et al., 2012).

ATR-FTIR Characterization. For the analysis of polymer functional groups in MP particles found in the samples, ATR-FTIR was used, operated according to experimental settings, in single reflection mode with a resolution of 8 cm^{-1}, and a range of 600 to 4000 cm^{-1}. The polymer types of plastics were identified through the functional groups that appear at specific wavenumbers generated by the interaction of infrared rays (Käppler et al., 2015). The process of identifying polymer types from MPs using ATR-FTIR involved analyzing the presence of prominent peaks. The MP identification scheme used the band region of 2780–2980 cm^{-1} ($CH/CH_2/CH_3$ group stretching vibrations), 1740–1800 cm^{-1} (C(O)O stretching vibrations), 1670–1760 cm^{-1} (C=O stretching vibrations), 1400–1480 cm^{-1} (CH_2 bending vibrations), and 1174–1087 cm^{-1} (CH_2 stretching vibrations) (Käppler et al., 2015; Löder et al., 2015). To avoid contamination, we adopted the method from Nuelle et al. (2014) by sterilizing all instruments for field and laboratory analysis and implementing procedural blanks. Doubly distilled water (DDW) was used throughout the study procedure.

Calculation of Microplastic Abundance. Microplastic abundance can be calculated by comparing the number of particles found using the following equation (Masura et al., 2015):

$$K = \frac{n}{m} \tag{1}$$

Where: K = Microplastic abundance (particles L^{-1}); n = Number of microplastic particles; m = Volume of samples (L)

Data Analysis. The total abundance of microplastics (particles L^{-1}) in each water sample was determined using one-way analysis of variance (ANOVA) and Duncan's post hoc test. The analysis was conducted at a significance level of $p<0.05$ using SPSS v23.

RESULTS AND DISCUSSION

Microplastic Abundance. The abundance of MPs found in the surface water samples showed the highest abundance at T1, with 202.5 particles L^{-1}. The order of abundance was T1 (25.88%)

> T3 (23.32%) > T4 (20.44%) > T2 (15.33%) > T5 (15.03%) (Figure 1).

The abundance of MP pollutants in the water samples follows the order T1 > T3 > T4 > T2 > T5. Statistically, the highest MP abundance in the water samples was found at station T1, which was not significantly different ($p>0.05$) from T3, but was significantly different ($p<0.05$) from T2, T4, and T5. This can be explained by the fact that station T1 is close to densely populated residential areas, T3 is a popular tourist area, and T4 is the Ombilin dock, the water exit point from Lake Singkarak. These findings are consistent with the study by Ding et al. (2019) which recorded high MP abundance in areas with high human activity. Furthermore, Su et al. (2016) stated that the high MP levels in this lake are due to surrounding human activities, including waste from washing machines, agricultural activities, commercial fishing, and tourism, all of which can potentially pollute lake waters. Stations T2 and T5 showed low microplastic abundance and were not significantly different ($p>0.05$), indicating that these stations are near rice fields and highways far from human activity (Liu & Su, 2014).

Identification of MP forms. The diversity of microplastic forms found in this study includes fragments, films, pellets, fibers, and foams, as shown in Figure 2**.**

Based on the forms of MP pollutants found in the water samples, fragments dominated with an abundance of 42.81%, followed by fibers at 30.36%, pellets at 23.64%, films at 2.87%, and foams at 0.32% (Figure 3).

The diversity of microplastic forms found in Lake Singkarak indicates various sources of MPs. These MPs originate from the physical degradation of larger plastic items into microplastics over time (Liu & Su, 2014). Fragment-shaped MPs are most commonly found on the water surface for several reasons: the degradation of large plastic products, domestic and

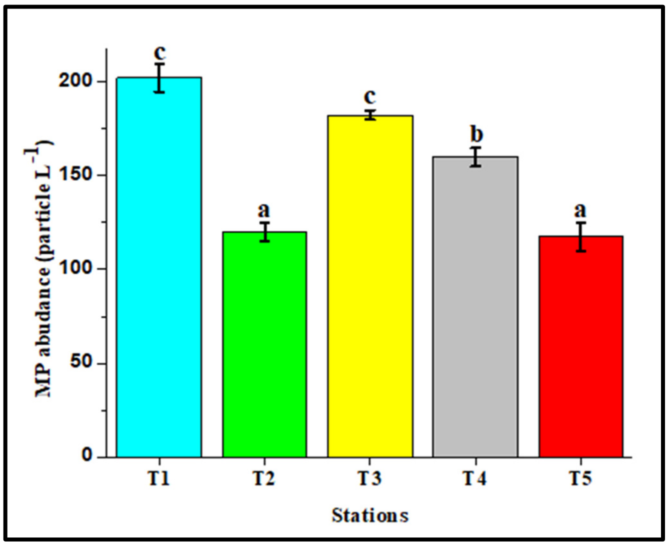

Fig. 1. MP abundance (particle L^{-1}) at different stations (T)

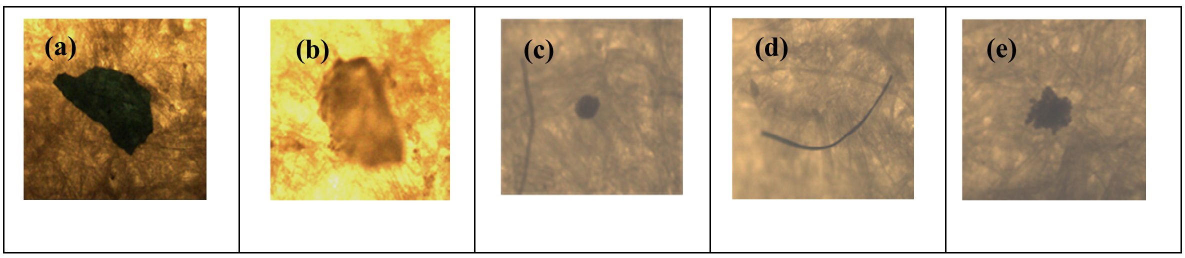

Fig. 2. Microplastic form identification at 100x magnification: (a) Fragment, (b) Film, (c) Pellet, (d) Fiber, (e) Foam

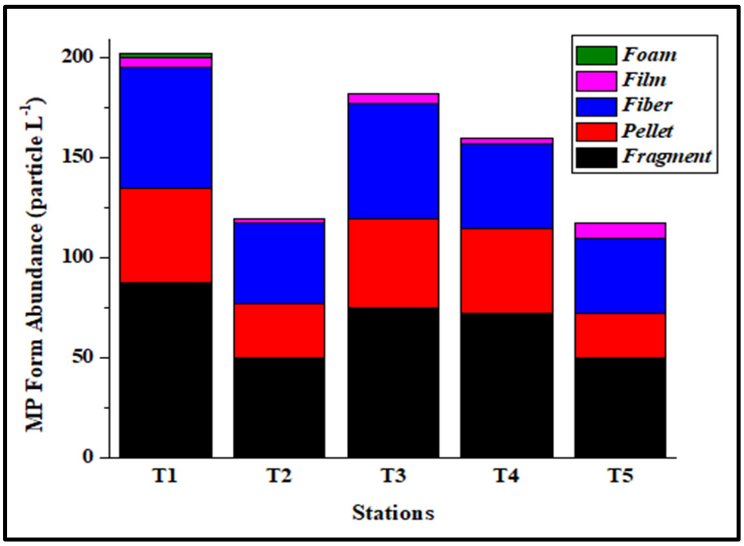

Fig. 3. MP Form Abundance (particle L^{-1}) at different stations (T)

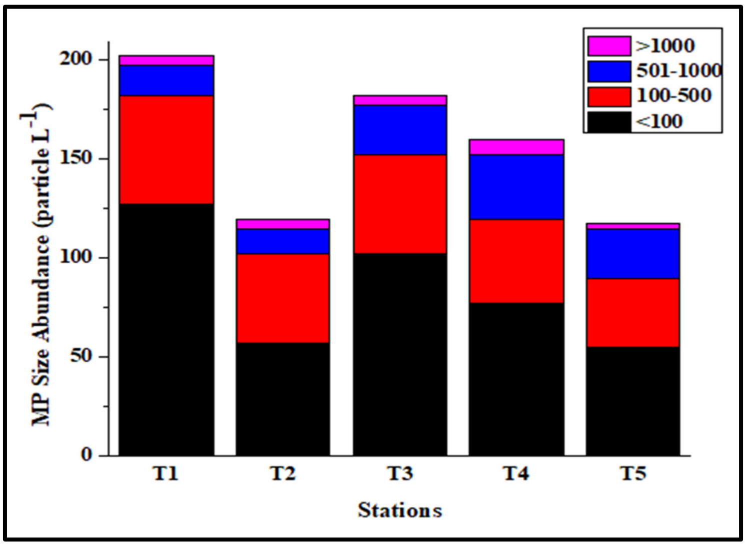

Fig. 4. MP size abundance (particle L^{-1}) at different stations

industrial waste, the durability of plastic fragments, water movement, and the lack of effective waste management systems. Large plastics such as bottles, bags, and containers often break into smaller fragments due to UV exposure, water waves, and mechanical processes. Domestic and industrial waste entering the aquatic environment frequently fragments during disposal and processing (Cole et al., 2013). Plastics have high resistance to biological degradation, so the formed fragments tend to persist in the water (Andrady, 2011). Currents and water waves help distribute MP fragments across various locations on the water surface (Law & Thompson, 2014). In many areas, inadequate waste management systems lead to more plastic waste being discarded into water bodies, where they further fragment (Kamani et al., 2024; Thompson et al., 2009).

Microplastic Sizes. Microplastics were grouped into several size categories, with the most frequently found in surface water samples being ≤100 µm (53.67%), followed by 101–500 µm (29.08%), 501–1000 µm (14.06%), and >1000 µm (3.19%) (Figure 4).

Microplastics sized ≤100 µm were most commonly found on the water surface for

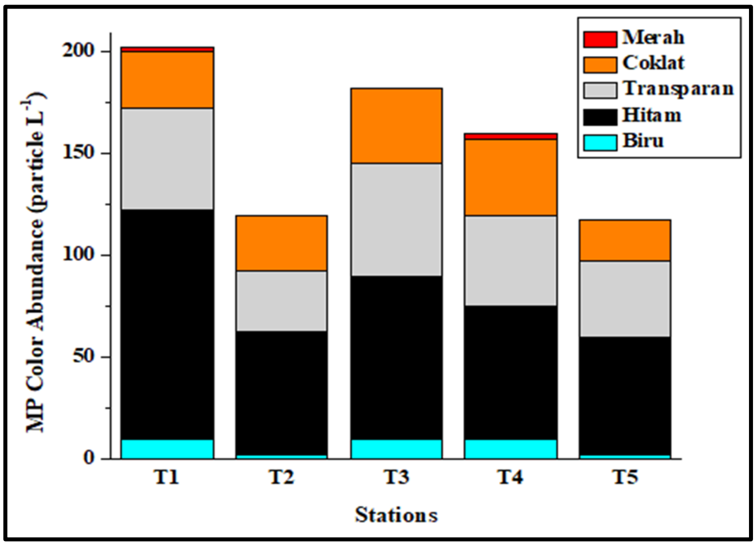

Fig. 5. MP color abundance (particle L^{-1}) at different stations

several reasons: the degradation of large plastics, their small size, primary MP sources, slow biodegradation processes, and industrial and domestic processes. Larger plastics fragment into smaller particles due to UV exposure, mechanical abrasion, and chemical reactions (Cole et al., 2013). Small MP particles are more easily dispersed by currents and water waves and are more resistant to breaking down into smaller fragments (Andrady, 2011). Cosmetic and personal care products often contain very small MPs that enter the environment directly without undergoing fragmentation (Kamani et al., 2024a; Leslie et al., 2022). Small MPs have a high surface area-to-volume ratio, which slows down degradation and allows these particles to persist longer in the environment (Law & Thompson, 2014). Many industrial and domestic processes produce small MP particles, either from the products used or from washing synthetic textiles (Browne et al., 2011).

Identification of MP Colors. The color of MPs can affect their ability to absorb or reflect sunlight. Based on Figure 5, the dominant colors of MPs in surface water samples were black (47.94%), followed by transparent (27.79%), brown (19.16%), blue (4.47%), and red (0.64%).

The causes of dark or black-colored MPs predominantly found on the water surface are as follows: the use of dark-colored plastics, degradation of vehicle tires, plastic waste incineration, contamination with other substances, and the stability of dark colors. Many daily-life products use dark or black plastics, such as car tires, electronic components, and household items. When these products fragment, they produce dark-colored MPs (Andrady, 2011). Vehicle tires are a major source of black-colored MPs. Tires contain black carbon materials that impart the dark color, and these particles are released into the environment through abrasion during vehicle use (Kole et al., 2017). The incineration of plastic waste can generate black or dark-colored MP particles. These particles are often disposed of into the environment through air and water (Ganji et al., 2024; Verma et al., 2016). Microplastics can get contaminated with dark-colored organic or inorganic materials, such as oil or mud, imparting a dark color to the MP particles (Kamani et al., 2024b; Rodrigues et al., 2018). Dark-colored plastics tend to be more resistant to UV degradation compared to light-colored plastics, thus persisting longer in the environment and more frequently found on the water surface.

Dark or black-colored MPs absorb more heat compared to light or transparent ones, which can increase temperatures and affect ecosystems. The black color indicates that the MPs originate from polystyrene (PS) or polypropylene (PP) with polycyclic aromatic hydrocarbons (PAHs), which have high pollutant absorption capabilities (Lie et al., 2018). Clear MPs originate from plastic fragments exposed to sunlight for too long, causing them to change color (Laksono et al., 2021). Microplastic color also affects UV absorption, where light or transparent MPs absorb less UV light compared to dark or black ones. High UV exposure can affect water quality, plankton and algae photosynthesis, and organisms dependent on UV light. Light-colored MPs are more easily consumed by zooplankton (Botterell et al., 2019).

Bright or transparent-colored microplastics ingested by organisms can affect optical effects on their bodies. Accumulated bright-colored microplastics in fish tissues can alter their visual appearance, affecting visual communication, including mating and defense against predators. Microplastic color also affects their ability to camouflage or be ingested by organisms. Bright-colored MPs are more visible to predators, while dark-colored MPs are more challenging to identify or separate from food. Microplastic color is influenced by environmental conditions and climate, as well as exposure to sunlight or UV rays, which can alter the color of MP particles. The photodegradation index of MP color can determine how long MPs remain in the water; the longer plastics remain in water, the more color degradation occurs (Deswati et al., 2023a; Sianturi et al., 2021).

The color variation of MPs originates from various types of plastics such as household waste, plastic bags, fishing nets, and cage ropes. The low recycling rate of these wastes leads to their accumulation in the environment. This study identified that the predominant color of microplastics is black, likely originating from food packaging, toys, kitchen utensils, electronics, and black plastic bags (Barboza et al., 2020; Deswati et al., 2023abc). Blue, brown, red, and transparent-colored MPs were also found, originating from food wrapping plastics, domestic laundry waste, or color changes due to prolonged exposure to sunlight (photoaging) (Liu & Su, 2014).

Identification of MP polymer types. The identification of MP polymer types found in water samples in this study was analyzed using ATR-FTIR to determine the functional groups of each particle and matched with a MP polymer library. Polymer type identification was not conducted for all MP particles, but a random selection was made from all particles found. Based on the polymer type testing results, MP polymers identified include polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), and polyvinyl chloride (PVC) (Figure 6-8).

The results of identifying the polymer type of transparent film MPs show that the particles are polyethylene (PE) MPs, as depicted in Figure 6.

The polymer type polyethylene (PE) from the sample is indicated by absorption peaks at wavenumbers 717.82 cm^{-1}, 1465.60 cm^{-1}, 2849.24 cm^{-1}, and 2915.92 cm^{-1}, corresponding respectively to the CH_2 rocking vibration, CH_2 bending, asymmetric CH_2 stretching, and symmetric CH_2 stretching regions (Deswati et al., 2024; Deswati et al., 2023; Wisna et al., 2023; Wu et al., 2021).

Figure 7. Identification result of plastic polymer type from red fragment. The identification result of the plastic polymer type from the red fragment indicates that the particle is MP of polypropylene (PP). This can be seen in Figure 7.

The polypropylene (PP) plastic polymer type from the sample is characterized by absorption peaks at wavenumbers 810.86 cm^{-1}, 1100.81 cm^{-1}, 1375.58 cm^{-1}, 1455.98 cm^{-1}, 2853.28 cm^{-1}, and 2916.67 cm^{-1}, which respectively correspond to CH rocking, CH_3 rocking, CH_3 bending, CH_2 bending, asymmetric CH_2 stretching, and symmetric CH_2 stretching vibrations (Deswati et al., 2024; Deswati et al., 2023; Wisna et al., 2023; Wu et al., 2021).

The results of identifying the types of plastic polymers from the transparent fragment and the brown fragment indicate that these particles are MPs of polyethylene terephthalate (PET), as seen in Figure 8.

The polyethylene terephthalate (PET) plastic polymer from the sample is characterized by the appearance of aromatic C-H bond vibration regions at wavenumbers 720.69 cm^{-1} (sample code b) and 718.54 cm^{-1} (sample code c), C-O stretching vibration regions at wavenumbers

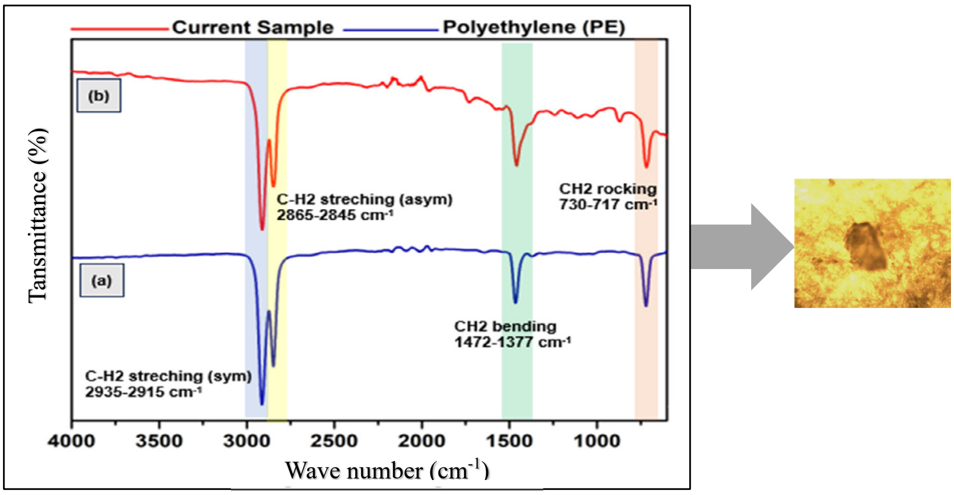

Fig. 6. Comparison of MP identification spectrum against standards:
(a) Standard polyethylene (PE), (b) Transparent film MP

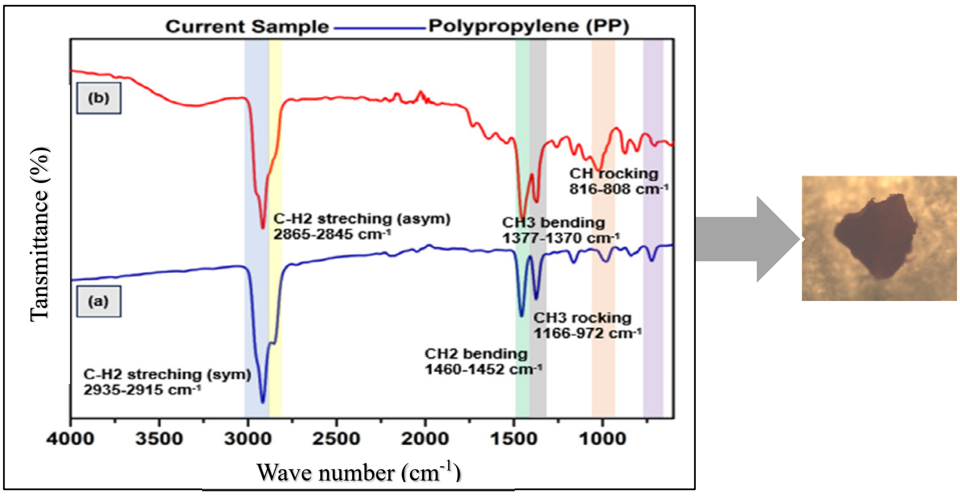

Fig. 7. Comparison of Identification Spectrum of Microplastic Against Standard:
(a) Standard polypropylene (PP), (b) Red fragment MP.

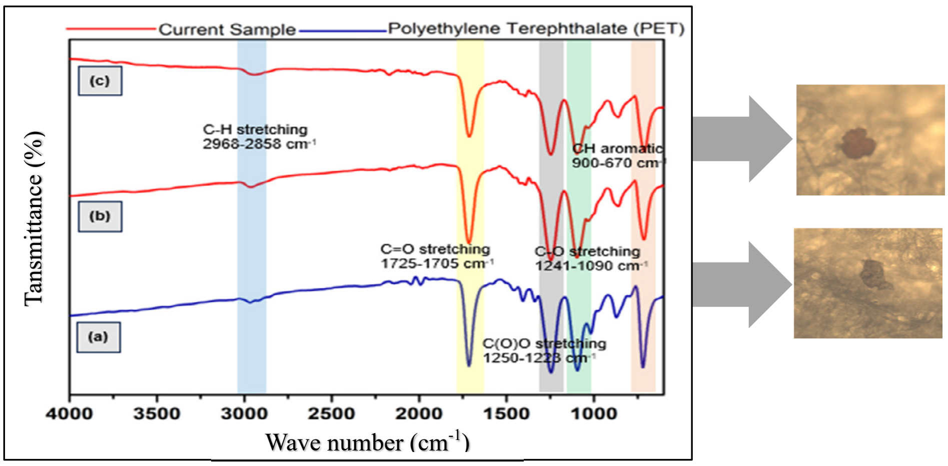

Fig. 8. Comparison of spectrum results from MP identification against standards: (a) Standard polyethylene terephthalate (PET), (b) Transparent MP fragment, (c) Brown MP fragment

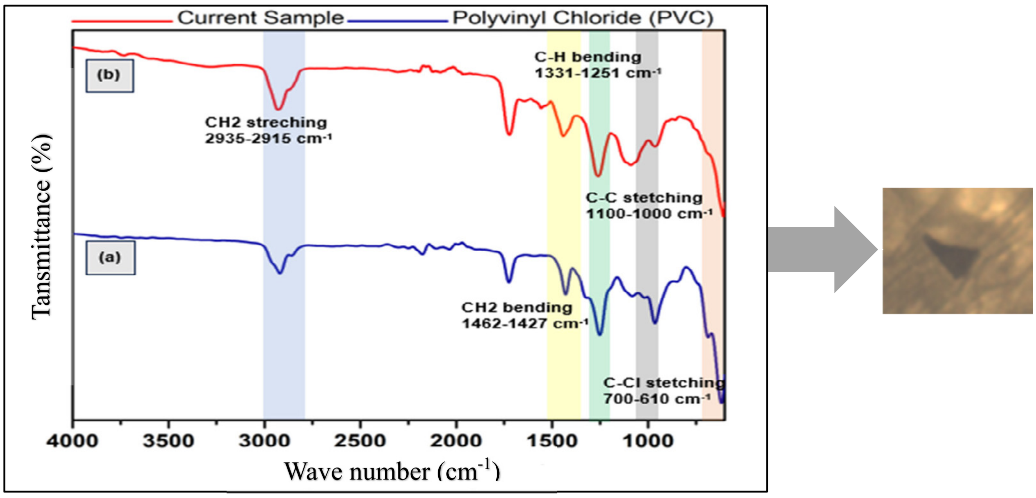

Fig. 9. Comparison of spectrum results from MP identification against standards: (a) Standard polyvinyl chloride (PVC), (b) Black MP fragment

1092.76 cm^{-1} (sample code b) and 1092.34 cm^{-1} (sample code c), C(O)O stretching vibration regions at wavenumbers 1244.27 cm^{-1} (sample code b) and 1244.78 cm^{-1} (sample code c), C=O stretching vibration regions at wavenumbers 1715.42 cm^{-1} (sample code b) and 1713.34 cm^{-1} (sample code c), and C-H stretching vibration regions at wavenumbers 2964.01 cm^{-1} (sample code b) and 2960.54 cm^{-1} (sample code c) (Deswati et al., 2024; Deswati et al., 2023; Wisna et al., 2023; Wu et al., 2021).

The results of the plastic polymer identification from the black fragment indicate that the particle is MP of polyvinyl chloride (PVC), as shown in Figure 9.

The polyvinyl chloride (PVC) plastic polymer from the sample is indicated by absorption peaks at wavenumbers 612.32 cm^{-1}, 1074.87 cm^{-1}, 1257.62 cm^{-1}, 1429.94 cm^{-1}, and 2920.95 cm^{-1}, corresponding to C-Cl stretching, C-C stretching, C-H bending, CH_2 bending, and CH_2 stretching vibrations, respectively (Wu et al., 2021).

CONCLUSION

This study reveals that Lake Singkarak, West Sumatra, Indonesia, has been exposed to microplastic (MP) pollution, with concentrations ranging from 117.5 to 202.5 particles L^{-1}. The findings indicate that plastic fragments are the most dominant form (42.81%), with black being the most common color (47.94%), and sizes ≤100 µm being predominant (53.67%). The microplastics detected consist of various polymer types, including polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), and polyvinyl chloride (PVC). These MPs are likely sourced from human activities around the lake, such as household, industrial, agricultural, and recreational waste. This study provides initial insights into the distribution and characteristics of microplastics in Lake Singkarak, which negatively impact aquatic organisms and water quality. The findings are expected to serve as a reference for better management strategies aimed at reducing the effects of microplastic pollution in freshwater ecosystems.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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