JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(10), 211–226
https://doi.org/10.12911/22998993/205822
ISSN 2299–8993, License CC-BY 4.0

Received: 2025.05.16
Accepted: 2025.07.15
Published: 2025.07.22

Ecological and health risks of microplastic contamination in edible fish from the Musi River Palembang, Indonesia

Khairil Anwar[1,2], Nurhayati Damiri[1*], Yuanita Windusari[3], Mohammad Zulkarnain[4]

[1] Doctoral Program of Environmental Science, Graduate School Universitas Sriwijaya, Jl.Padang Selasa No. 524, Bukit Besar of Palembang, South Sumatra, Indonesia
[2] Environmental Health Department, Ministry of Health Polytechnic of Palembang Jl. Mawar 2711 Palembang
[3] Public Health Department Faculty of Public Health, Universitas Sriwijaya, Jl. Raya Palembang, Prabumulih Km 32 Indralaya, Ogan Ilir, Sumatera Selatan, Indonesia
[4] Medical Department Faculty of Medicine, Universitas Sriwijaya, Jl. Raya Palembang, Prabumulih Km 32 Indralaya, Ogan Ilir, Sumatera Selata, Indonesia
* Corresponding author's e-mail: nurhayati@fp.unsri.ac.id

ABSTRACT

Microplastic contamination in aquatic environments has become an urgent environmental issue, particularly in riverine and coastal areas. The Musi River in Palembang, Indonesia, is one of the water bodies at risk of microplastic pollution, which can affect ecosystems and human health through the food chain. This study aimed to evaluate the distribution of microplastics in fish, ecological risks, and public health risks in Palembang, Indonesia. Results showed that all ten fish species studied contained microplastics, with *Barbonymus schwanenfeldii* showing the highest level of contamination, with 25 particles per fish in the intestines. Fragment shaped and black colored microplastics were the most dominant, with an average abundance of 12.6 particles per fish and sizes ranging from 0.1 mm to 5 mm. Identified microplastic polymers included polyethylene terephthalate (PET), polyethylene (PE), and polyvinyl chloride (PVC), categorized as medium risk based on the polymer hazard index (PHI), while polypropylene (PP) and polystyrene (PS) were categorized as low risk. These findings reflect the complexity of microplastic pollution and its ecological risks. The study also indicated that the public consuming fish from the Musi River is still within the low-risk category regarding health impacts. These findings emphasize the importance of continuous monitoring and effective plastic waste management to reduce long-term environmental and public health impacts.

Keywords: microplastics, Musi River, edible fish, ecological risk, public health risk.

INTRODUCTION

Approximately 320 million tons of plastic are produced annually worldwide (Ragusa et al., 2021), reflecting the extensive use of plastics in modern society. However, the durability and resistance of plastic materials have led to serious environmental issues, such as the accumulation of plastic waste in landfills, freshwater bodies, and oceans. About 8 million tons of plastic waste enter the oceans each year (Rios Mendoza et al., 2019). Once in aquatic environments, plastic can degrade due to mechanical stress, radiation, and microbial activity (Silva et al., 2018). Microplastics are plastic particles less than 5 mm in diameter, originating from various sources, including the degradation of larger plastic items (Khan et al., 2020). In Indonesia, plastic waste pollution has reached a critical level. According to Jambeck et al. (2015), microplastics represent a particularly hazardous form of plastic pollution due to their environmental and human health impacts. The entry of microplastics into freshwater systems can be attributed to various factors, including river hydrodynamics that facilitate the transport of these particles from urban and rural areas into rivers and lakes. Jaikumar et al. (2022) emphasized that the ecological implications of microplastics in freshwater ecosystems remain less understood compared to those in marine environments, thus necessitating more comprehensive evaluations. Rivers therefore serve not only as transport pathways for microplastics but also as deposition sites, further complicating their distribution and potential for bioaccumulation in aquatic biota (Tirkey et al., 2022). The ecological risks posed by microplastics are significant. Numerous studies have detected small microplastics (< 300 μm) in various freshwater fish species, including those found in Jakarta Bay (Henny et al., 2023). The ingestion of microplastics can lead to physical deformities and health impairments in fish; such contaminants may cause mechanical injury, reproductive disorders, and behavioral changes (Badea et al., 2023). Moreover, harmful additives leaching from microplastics may increase toxicity in fish and potentially disrupt entire food webs in freshwater ecosystems (Yamen et al., 2024). This situation raises serious concerns, as not only fish but also organisms at higher trophic levels may be affected.The implications of microplastic contamination extend beyond aquatic life, posing potential risks to human health. Fish that ingest microplastics may bioaccumulate these particles, ultimately threatening humans as end consumers (Curtean-Bănăduc et al., 2023). Since these contaminants can enter the human food chain, there is growing concern over associated health risks, including digestive issues and endocrine disruption (Ghosh et al., 2023). The concern over microplastics also impacts the economy, particularly the fisheries and tourism sectors (Bhardwaj and Yadav, 2023).

One of the most immediate economic impacts of microplastics is their detrimental effect on industries that heavily rely on marine ecosystems. The fisheries sector has reported a significant decline in both the quality and quantity of catches due to the presence of microplastics in marine environments. Seafood contamination has raised health concerns among consumers, leading to reduced sales and potential economic losses for local fisheries (Ghosh et al., 2023). From a social perspective, the widespread presence of microplastics has triggered concerns regarding public health. Researchers have linked microplastic exposure to various health issues, including respiratory problems and digestive disorders, which may erode consumer confidence and increase healthcare costs (Ghosh et al., 2023; Senathirajah and Thavamani, 2023). Alarming data indicate that humans may ingest substantial amounts of microplastics each week, raising critical questions about their health impacts and highlighting the need for further research on their long-term effects (Otorkpa and Otorkpa, 2024). The persistent presence of microplastics in the environment, compounded by their non-biodegradable nature, leads to increasing accumulation within ecosystems – particularly in habitats that are highly sensitive to pollution, such as estuaries and oceans (Grace et al., 2022).

A study by Aunurohim (2023) revealed the presence of microplastics in the gastrointestinal tracts of commercially harvested marine fish in Indonesia, demonstrating that these pollutants can cause ecological harm through ingestion by marine biota even in waters distant from primary pollution sources. The effects of microplastic consumption by fish are alarming, as they may lead to severe physiological disorders. The presence of microplastics in fish digestive systems can trigger physiological stress, including inflammation and the risk of starvation due to gastrointestinal blockage (Hasegawa and Nakaoka, 2021). Beyond their direct impact on fish, there is increasing concern about the potential entry of microplastics into the human food web. Consumption of contaminated aquatic organisms may pose health risks, particularly because microplastics have the ability to absorb and transport hazardous chemicals into the human body (Daud et al., 2024). A comprehensive study by Pramaningsih et al. (2023) highlighted the growing health risks associated with seafood consumption, particularly in Indonesian coastal communities that heavily depend on fish and marine products as staple food sources. The presence of microplastics in economically important fish species not only affects the environment but also creates socio-economic challenges related to food safety and public health. The Musi River, the longest river in South Sumatra, Indonesia, serves as a habitat for a diverse biological community, including various fish species that play a vital role in the ecosystem and local economy. The composition of fish in this river reflects the ecological condition of the water body and the influence of human activities on the biodiversity of this habitat. This study aims to evaluate the distribution of microplastics and their potential ecological risks in fish from the Musi River, as well as to assess the associated health risks for the population in Palembang City linked to the consumption of fish originating from the Musi River.

METHODS AND MATERIALS

Research methodology

This study was conducted from May to August 2024 and involved two main sample groups: (1) fish samples from the Musi River in Palembang City, comprising 10 commonly consumed fish species (Figure 1), and (2) human respondents totaling 96 individuals. The inclusion criteria for respondents were: residing within 100 meters from the banks of the Musi River in Palembang, having lived in the area for over 10 years, being over 40 years of age, and regularly consuming fish sourced from the Musi River. The data collected included age, body weight, fish species consumed, and fish consumption frequency, which was categorized into four groups: 1–2 times per week, 3–4 times per week, 5–6 times per week, and daily. Fish sampling locations were distributed along the course of the Musi River in Palembang and samples were obtained using fishing methods. Fish identification in this study included morphological characteristics such as color, shape, and size of microplastics within the fish body. The polymer types of microplastics detected were characterized using spectroscopy, and the ecological risk potential was assessed based on the abundance and types of polymers found, as well as the health risks associated with the consumption of fish contaminated with microplastics.

Microplastic extraction

The procedure for extracting microplastics from fish was adapted from the method described by Karami et al. (2017). The length and weight of each fish were recorded prior to further processing. All equipment used was thoroughly cleaned with distilled water to prevent contamination. The fish samples were rinsed with deionized water, weighed to determine wet weight. The process of plastic extraction from fish involved dissecting the fish and collecting the intestinal organs, which were then treated with a KOH solution to digest biological tissues and isolate microplastics. Subsequently, filtration and density separation were performed to collect the microplastics. Then dried at 60 °C until a constant weight was achieved, and reweighed to obtain the dry weight. The dried samples were placed in 500 mL beakers, followed by the addition of 20 mL of 30% hydrogen peroxide (H_2O_2) solution. The digestion process was carried out by heating the mixture to 40 °C while stirring with a magnetic stirrer at 250 rpm, followed by incubation in an oven for 30 minutes. After digestion, 400 mL of saturated sodium chloride (NaCl) solution (5 M) was added, the mixture was homogenized for 15 minutes, and then allowed to settle for 24 hours to separate the microplastic-containing fraction. The supernatant was filtered using Whatman No. 42 filter paper (2.5 µm pore size) with the aid of a vacuum pump. The filter paper was then dried in sterile Petri dishes for subsequent microplastic identification.

Microscopic examination

Microplastic identification was conducted microscopically on the extracted and dried particles based on morphological characteristics such as shape, color, and size. Observations were performed using a Meiji B-350 stereo optical microscope equipped with an integrated digital camera connected to Motic Image Plus 3.0 software, which enhanced analytical accuracy. Observations were carried out at 100x

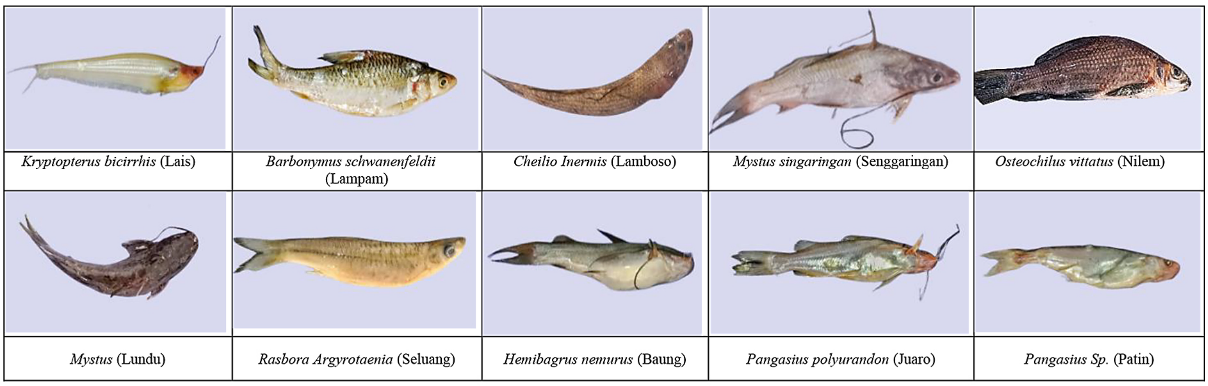

Figure 1. Fish species identified from the Musi River

magnification, allowing for clear visualization of microplastic particles. The number of particles was manually counted on the monitor display, and each particle was classified based on its morphological features (Suparno et al., 2024). The polymer types of microplastics were verified using a Fourier Transform Infrared (FT-IR) spectrometer (PerkinElmer Frontier).

Microplastic abundance calculation

Microplastic abundance was calculated following the method developed by Wang and Wang (2018), which enables the estimation of microplastic particle numbers based on the volume or mass of the analyzed sample. This approach involves comparing the number of identified microplastic particles in the sample to the total sample volume or mass, thus providing a representative quantitative estimate. This method plays a critical role in generating consistent and comparable data across studies, particularly in research investigating the distribution of microplastics in various environmental settings

Ecological risk assessment of microplastics in fish

One of the approaches used to assess the ecological risk potential of microplastics is the Polymer Hazard Index (PHI), which was recently developed (Ranjani et al., 2021; Huang et al., 2022). The polymer risk assessment for microplastics was conducted using the following formula:

$$Polimer\ Hazard\ Indeks\ (PHI) = \sum S_n \times P_n \quad (1)$$

where: *Sn* represents the hazard score of a given polymer, and *Pn* is the proportion of each polymer type. The PHI values are classified into five hazard levels (Lithner et al., 2011): 0–1 (Level I): Minor, 1–10 (Level II): Medium, 10–100 (Level III): Considerable, 100–1000 (Level IV): High, 1000 (Level V): Very high.

In addition, the coefficient of microplastic impact (CMPI) was assessed to determine the impact of different microplastic categories, derived from the relative contribution of specific microplastic forms (e.g., pellets or fibers) (Rangel-Buitrago et al., 2021). The CMPI indicates the correlation between the total number of a specific microplastic type and the overall number of microplastics identified in a given sampling unit. CMPI is calculated using the formula:

$$CMPI = \frac{Specific\ MP}{Shape\ Total\ MPs} \quad (2)$$

where: *CMPI* is classified into four categories: 0.0001–0.1 (minimum), 0.11–0.5 (averange), 0.51–0.8 (maximum), 0.81–1 (extreme).

Human health risk assessment from microplastic exposure

To estimate the daily intake of microplastics by humans, the estimated daily intake (EDI) was calculated by considering the concentration of microplastics in the edible tissues of fish, along with key population data such as consumption frequency, average body weight, and average lifespan (Katsikantami et al., 2019). According to Bassey and Chukwu (2019), EDI can be calculated using the following formula:

$$EDI\ (mg/kg/day) : \frac{EF \times ED \times IR \times C}{WAB \times ATn} \quad (3)$$

where: *EF* is the exposure frequency, *ED* is the exposure duration, *IR* is the ingestion rate of fish, *C* is the concentration of microplastics in fish, *WAB* is the average body weight (kg), *ATn* is the averaging time for non-carcinogens.

Furthermore, to assess the general human health risk from consuming fish contaminated with microplastics, the target hazard quotient (THQ) was calculated. THQ represents the ratio of exposure (microplastic concentration in edible tissues) to the tolerable intake level (reference dose, RfD) for microplastics. A THQ value < 1 indicates a low or negligible health risk for the exposed population. A THQ value > 1 suggests moderate to high health risk (Sparling, 2016). The formula for THQ is as follows (Djedjibegovic et al., 2020):

$$THQ = \frac{EF \times ED \times IR \times C}{RfD \times WAB \times ATn} \times 10^{-3} \quad (4)$$

where: *THQ* is measurement of non-carcinogenic health risks due to exposure to hazardous compounds, *EF* is frequency of exposure, ed is duration of exposure, *IR* is level of fish consumption, *C* is concentration of microplastics in fish, *RfD* is reference dose for microplastics (e.g., for Polyethylene Terephthalate/terephthalic acid and ethylene glycol), *WAB* is mean body weight (kg), ATn is time averaging for non-carcinogens (Djedjibegovic et al., 2020).

RESULTS AND DISCUSSION

Morphological characteristics, color, size and total abundance of microplastics in fish samples

All fish species identified from the Musi River in this study were found to contain microplastics. The morphological types of microplastics observed included fragments (45%), fibers (30%), films (20%), and pellets (5%) (Figure 3a and Figure 4). These diverse forms indicate various sources of contamination arising from anthropogenic activities along the river basin. Fragment-shaped microplastics are likely derived from household and plastic manufacturing waste; fibers originate from fishing nets and ropes used by local fishermen; films stem from industrial wrappers, agricultural plastics, and single-use plastic bags. The expansion of aquaculture and agriculture sectors contributes to the prevalence of outdated fishing equipment, such as nets, which also plays a role in the dominance of fiber-type microplastics (Xu et al., 2021). Moreover, according to Browne et al. (2011), the high fiber content may result from laundry wastewater processed by local wastewater treatment plants. Previous studies have shown that the form and type of microplastics ingested by fish vary depending on environmental conditions. Yamen et al. (2024) highlighted that in freshwater systems in Malaysia, fibers and fragments were the most frequently ingested microplastics by fish, accounting for 55.6% and 25.9%, respectively. Similar findings were reported in the waters of Malimono City, Surigao Del Norte, Philippines, where fragments, films, fibers, beads, and polymers such as polyethylene and polypropylene were found in the digestive tracts of various fish species (Masud and Cable, 2023; Gómez et al., 2023). In contrast, a study in the rivers of Bangladesh reported that 73.3% of sampled fish contained microplastics, with fibers being the predominant type of contaminant (Siddiqa et al., 2025).

The most dominant microplastic color found in fish was black, followed by brown, transparent, red, and blue (Figure 3b). Variations in microplastic color in fish from the Musi River may reflect diverse sources of plastic pollution. Colored microplastics originate from commonly used plastic products such as clothing, packaging, fishing nets, and others (Wang et al., 2017). The weathering of these items can result in black-colored microplastics becoming dominant in aquatic ecosystems (Wu et al., 2018). In addition, the prevalence of black microplastics may be attributed to the widespread use of black plastics in consumer products and food packaging, particularly garbage bags a finding supported by previous research (Rahmani et al., 2023). Improper disposal of plastic waste and debris from industrial activities into waterways may also contribute to the presence of colored microplastics. Fish may inadvertently ingest these colorful particles during normal feeding behaviors (Islam, 2022).

The average abundance of microplastics per fish species was 12.6 particles/fish in the intestine. *P. polyuranodon* exhibited the highest number of microplastics, with 25 particles per fish, whereas *Pangasius sp.* had the lowest, with only 5 particles (Figure 3c). The abundance of microplastics in fish samples from the Musi River in Palembang was higher than that reported in Thailand, where Labcom et al. found an average of 7.87 microplastic particles per fish sample from the Mun River, indicating considerable accumulation in freshwater species (Labcom et al., 2024). Domestic activities such as laundry may exacerbate microplastic pollution, as synthetic clothing releases microfibers that ultimately enter aquatic environments (Wei et al., 2022). Differences in microplastic abundance among fish species in the Musi River may be attributed to multiple factors, including species-specific traits, habitat, human activities near the river, and plastic pollution sources. Certain species, especially those at lower trophic levels or with omnivorous diets, exhibited higher microplastic ingestion rates due to feeding strategies such as filter -feeding or benthic foraging (Bogdan et al., 2022). Additional factors influencing microplastic concentration in fish include feeding behavior and body size. This study suggests that dietary intake and nutritional condition play key roles in microplastic accumulation. Larger fish may exhibit higher ingestion rates, a trend especially evident in macroinvertebrates but not uniformly observed across all fish species (Ng et al., 2024). The size of microplastics found in fish species ranged predominantly from 0.1 mm to 5 mm, with some species also containing particles smaller than 0.1 mm. Notably, 10% of *H.*

nemurus and 20% of *C. inermis* contained microplastics smaller than 0.1 mm (Figure 3d). The variation in microplastic size detected in Musi River fish samples can be attributed to factors such as the source of microplastics, degradation mechanisms, and interactions between fish and their aquatic environment. Larger microplastics undergo biodegradation over time, and smaller particles are considered more hazardous than larger plastic items (Andrady, 2011). Lei et al. (2018) reported that smaller microplastic particles have a higher capacity to adsorb hydrophobic organic contaminants from water (Devriese et al., 2017). Furthermore, fish feeding strategies significantly influence the variation and size of ingested microplastics. Different species employ distinct feeding mechanisms, leading to different ingestion rates. Filter feeders and omnivorous species tend to ingest more microplastics compared to carnivorous species (Zhang et al., 2023). This difference may arise from microplastic particles mimicking natural prey in size and shape, thereby increasing the likelihood of ingestion (Nasution et al., 2024). Larger fish are more likely to ingest greater quantities of microplastics due to their feeding habits, which involve consuming more water and sediment that may contain microplastics resulting in higher detected concentrations within their systems (Ding et al., 2023).

Identification of microplastic polymer types in fish samples

Fourier transform infrared (FTIR) spectroscopy using the Perkin Elmer Frontier system is a reliable method for identifying and distinguishing various types of plastic polymers. The FTIR results (Figures 4, 5, and 6) revealed distinctive absorption peaks corresponding to functional groups of different polymer types detected in each fish species. In *P. polyuranodon*, characteristic absorption peaks were observed at wavenumbers 2919.30 cm^{-1} and 2850.03 cm^{-1}, indicating C–H stretching vibrations, a typical signature of polyethylene (PE) polymer. Additional peaks around 1463.97 cm^{-1} and 719.65 cm^{-1} further confirmed the ingestion of PE microplastics. Similarly, in *K. bicirrhis*, the spectral pattern showed peaks at 2917.50 cm^{-1} and 2850.06 cm^{-1}, along with strong absorption bands at 1457.80 cm^{-1} and 719.01 cm^{-1}, which

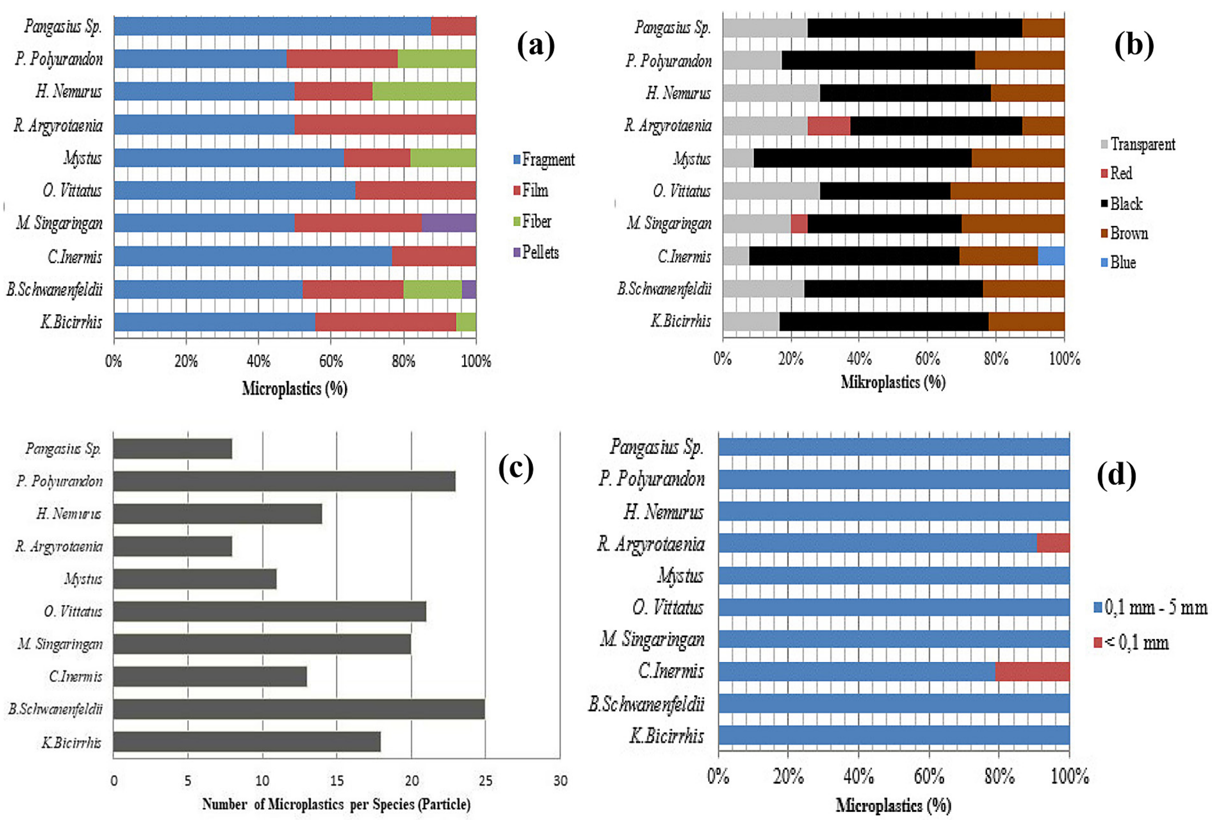

Figure 2. Shape (a), color (b), abundance (c) and size of microplastics (d) found in fish species in the Musi River

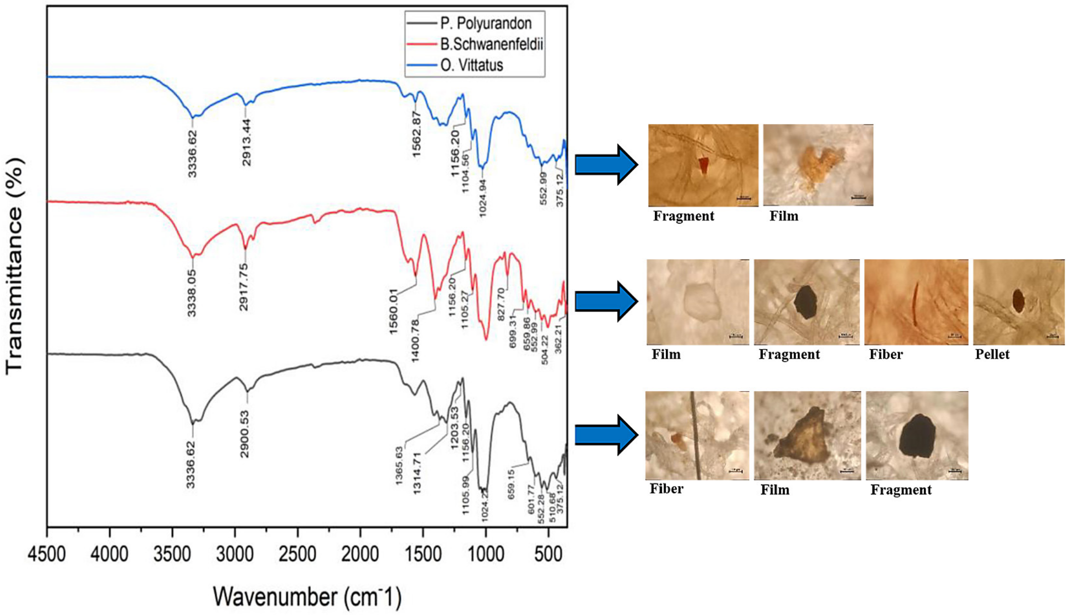

Figure 3. FTIR analysis and forms of microplastics in the *Pangasius polyurandon* (Juaro), *Barbonymus schwanenfeldii* (Lampam) and *Osteochilus vittatus* (Nilem)

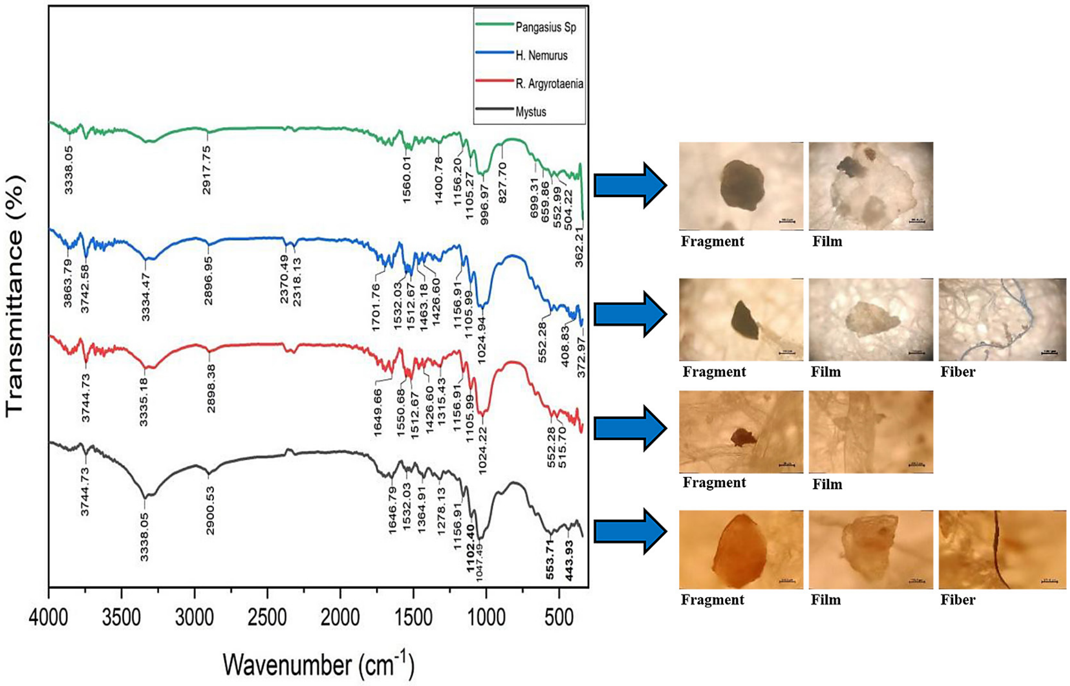

Figure 4. FTIR analysis and microplastic forms in *Pangasius sp* (Patin), *Hemibagrus nemurus* (Baung), *Rasbora Argyrotaenia* (Seluang) and *Mystus* (Lundu)

are highly indicative of polyethylene. In *Pangasius sp.*, the FTIR spectra showed peaks at 2917.76 cm^{-1} and 2849.55 cm^{-1}, corresponding to aliphatic C–H stretching, as well as peaks at 1463.61 cm^{-1} and 720.43 cm^{-1}, which are also characteristic of PE. The species *Mystus* displayed strong peaks at 2914.12 cm^{-1}, 2849.03cm^{-1}, and 1457.91 cm^{-1}, which also suggest the presence of polyethylene. Peaks below 800 cm^{-1} indicated the presence of saturated hydrocarbon chain structures, suggesting that these species had likely ingested plastic particles originating from plastic bags, films, or single-use plastic products.

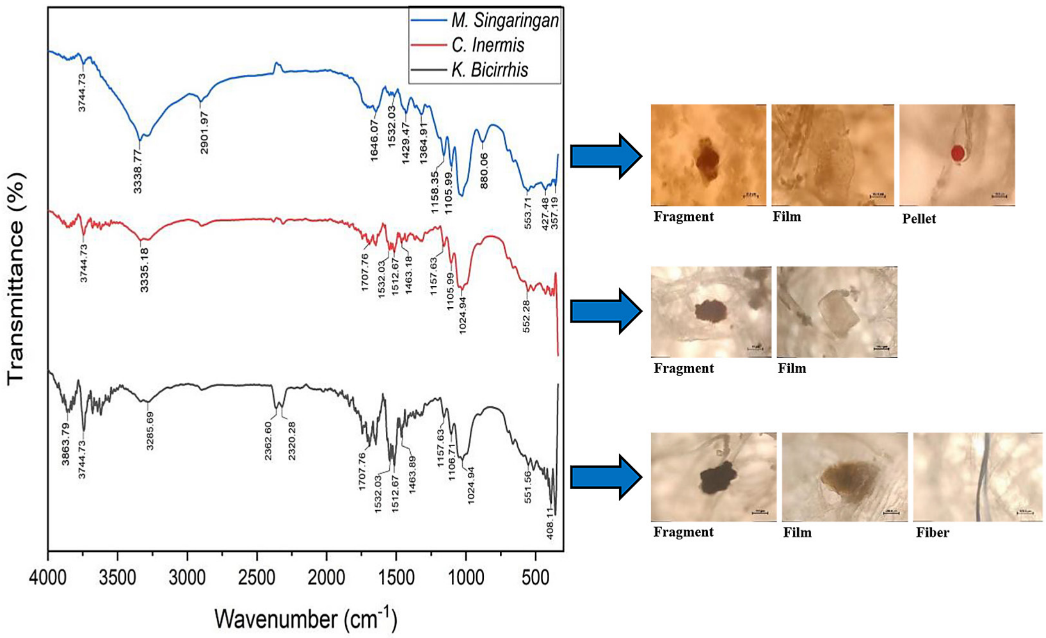

Figure 5. FTIR analysis and microplastic forms in *Mystus singaringan* (Senggaringan), *Cheilio Inermis* (Lamboso) and *Kryptopterus bicirrhis* (Lais)

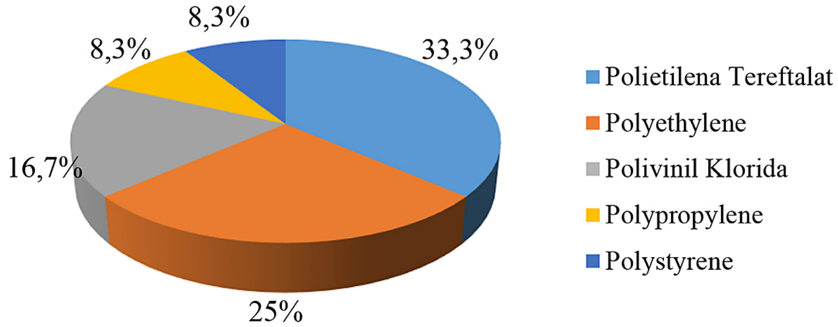

Figure 6. Percentage of dominant microplastic polymers in 10 identified fish species

Polyethylene (PE) can be reliably identified through FTIR spectroscopy due to its distinct absorption pattern. Absorption peaks in the range of 2936–2915 cm^{-1} correspond to symmetric C-H stretching vibrations, while those in the range of 2865–2845 cm^{-1} indicate asymmetric C-H stretching. In addition, bending vibrations are detected between 1472–1377 cm^{-1}, and rocking vibrations appear between 730–717 cm^{-1}, all of which confirm the presence of PE structures in the sample (Morgado et al., 2021).This polymer is commonly found in plastic bags and household packaging, indicating exposure to domestic waste. The presence of PE in aquatic environments can pose serious threats to fish health if ingested. Accumulation of PE in the digestive tracts of fish may interfere with digestion and nutrient absorption, potentially compromising the overall health of the fish (Dehaut et al., 2016). Research has demonstrated that microplastics within fish can cause physiological stress, leading to weight loss, stunted growth, and developmental issues (Vo and Pham, 2021). Over time, microplastic accumulation in fish may result in bioaccumulation and negative health impacts, including risks to human consumers who eat these fish (Gola et al., 2021).

In *B. schwanenfeldii*, significant peaks were observed at 2920.45 cm^{-1} and 2851.17 cm^{-1}, along with a strong absorption band at 1736.68 cm^{-1}, indicating the presence of polyethylene terephthalate (PET), characterized by the carbonyl (C=O) stretching vibration. Similarly, in *M. singaringan*, FTIR spectra revealed peaks at 2914.52 cm^{-1} and 2847.57 cm^{-1}, representing aliphatic C-H stretching, as well as additional peaks at 1737.68 cm^{-1}

(C=O stretching) and 1463.97 cm⁻¹, all pointing toward the identification of PET polymer. The species *H. nemurus* exhibited strong peaks at 2914.57 cm^{-1} and 2848.70 cm^{-1}, as well as at 1738.95 cm^{-1} (C=O stretching), further confirming the presence of PET. FTIR analysis of *R. argentata* showed characteristic absorption peaks at 2913.78 cm^{-1}, 2849.50 cm^{-1}, and 1737.02 cm^{-1}, also indicative of PET or other vinyl-based polymers. A prominent peak at 1714 cm^{-1} indicated the presence of carbonyl (C=O) groups, consistent with the ester bonds that form the structural backbone of PET (Radadiya et al., 2023).

These microplastic polymers likely originate from synthetic clothing or food packaging, suggesting that the fish were exposed to plastics from domestic waste or packaging sources. PET is frequently found in the gastrointestinal tracts of freshwater fish and raises concerns over ingestion levels and its potential health effects. A study conducted in Slovenia revealed that PET was among the most common microplastics found in species such as *Rutilus rutilus*, reflecting widespread microplastic contamination in freshwater habitats (Bogdan et al., 2022). These findings are consistent with a systematic review that identified PET as a common pollutant in both freshwater and marine fish, suggesting that its ingestion may result in bioaccumulation and potential trophic transfer (Oza et al., 2024). The assimilation of microplastics by fish can cause toxicological effects, including inflammation and disruptions to feeding behavior, ultimately affecting biodiversity and fish population dynamics (Dhaka et al., 2022). Long-term consumption of PET may also impair fish immunity, hinder reproductive performance, and negatively impact overall health, thereby influencing fish population sustainability and aquatic food web stability (Vo and Pham, 2021).

In *C. inermis*, significant absorption peaks were observed at 2916.47 cm^{-1} and 2850.00 cm^{-1}, along with strong absorption at 1729.72 cm^{-1} and 1461.52 cm^{-1}, supporting the presence of polyvinyl chloride (PVC) polymer. The peak range of 2906–2851 cm^{-1} has been reported as characteristic of C-H stretching vibrations, confirming the polymer structure of PVC (Zhu et al., 2024). These findings suggest that the fish may have ingested microplastics originating from hard plastic materials or synthetic fibers. PVC is known for its resistance to degradation, making it more likely to accumulate gradually within aquatic ecosystems, thereby posing both direct and indirect risks to fish health and biodiversity (Chen et al., 2024). Experimental studies have shown that exposure to PVC microplastics can alter fish growth and reproductive capacity (Wang et al., 2024). Additionally, PVC microplastics can cause significant biological effects on fish populations. Salimi et al. (2022) reported that PVC microplastics induced the formation of reactive oxygen species (ROS) in human lymphocytes but not in fish lymphocytes, suggesting interspecies variation in susceptibility. These differences in sensitivity indicate that PVC pollution may affect fish health in river ecosystems through multiple mechanisms.

In *O. vittatus*, spectral peaks were detected at 3295.02 cm^{-1} and 2917.44 cm^{-1}, corresponding to O-H and C-H stretching, respectively. These are indicative of polyurethane or other oxygenated plastic types such as PET, PP, and PS. The physiological impact of polystyrene polymers on fish has been demonstrated through histological changes in the liver of *Heteropneustes fossilis* following exposure to polystyrene nanoparticles, indicating direct toxic effects on organs that are highly sensitive to chemical pollutants (Bhowmick and Kumar, 2024). Furthermore, Hayati et al. (2024) found that exposure to polystyrene nanoplastics negatively affected cytokine levels and the reproductive system of male Nile tilapia (*Oreochromis niloticus*), suggesting endocrine disruption and overall health deterioration. Moreover, polystyrene microplastics may disrupt hormonal balance in fish, particularly affecting the histological structure of gonads, potentially leading to apoptosis (cell death) in gonadal cells. These hormonal disturbances may impair reproductive performance and population dynamics, thereby threatening the sustainability of fish stocks (Laily et al., 2023).

Distribution of microplastic polymer types identified in 10 fish species from the Musi River

The distribution of microplastic polymer types identified in the 10 fish species from the Musi River showed that PET was the most frequently detected polymer, accounting for 33.3% of the total. PET is widely used in food and beverage packaging materials (e.g., plastic bottles), suggesting its likely origin from domestic and industrial waste. PE and PVC were also found in considerable proportions, at 25% and 16.7%, respectively. These polymers are commonly found in everyday plastic products such as plastic bags, pipes, and cables, reflecting their contribution to microplastic pollution in aquatic environments. Other polymers such as PS and PP were also detected, though in smaller proportions, each representing 8.3% of the total. Despite their lower prevalence, the presence of these polymers is significant, as they indicate diverse microplastic sources, including single-use food containers (PS) and flexible packaging or household items (PP). A study conducted along the banks of the Minho River found 36 different polymers in fish microplastics, including cellulose acetate, polypropylene, polyethylene, polyacrylate, and polyester (Guilhermino et al., 2021). The findings of the current study are also consistent with research on Nile tilapia (*Oreochromis niloticus*), which identified PE, PA, and PET as common polymers (Deswati et al., 2025). Similar results were observed in studies of commercial fish species from the central Black Sea, where polyethylene and polypropylene were identified as the dominant polymers (Bilgin et al., 2025).

Ecological risk index of microplastics in fish species

The ecological risk index of microplastics in fish species was evaluated using the Polymer Hazard Index (PHI) (Table 1). This study assessed the potential ecological risks of microplastic polymers found in fish species from the Musi River in Palembang. The findings revealed that PE exhibited the highest PHI value (2.75) due to the relatively high hazard score of the ethylene monomer (11) and its mass contribution of 25%. This underscores the potential hazard posed by the monomer before polymerization or through degradation or residual monomer release during use or recycling. PVC had a PHI of 1.76, despite contributing only 16.7% to the polymer composition. PVC is known to be a carcinogenic compound, with a high hazard score (10.55), resulting in a medium risk category. This is especially relevant for applications such as children's toys, food packaging, or water pipes. Polyethylene terephthalate (PET), while generally considered safe for food and beverage packaging, had a PHI of 1.33 due to the presence of terephthalic acid and ethylene glycol. Although these monomers are less toxic than others, their relatively high mass contribution still influences the overall hazard index.

PP and PS both exhibited PHI values of less than 1, placing them in the Minor Risk Category. Nevertheless, microplastic particles composed of these polymers may still cause physical disturbances such as gastrointestinal blockage or intestinal tissue damage, particularly under conditions of high exposure. Therefore, a PHI score below 1 should not be overlooked when assessing overall ecological risk. It is crucial to evaluate the chemical toxicity of different polymer types and to quantify microplastic abundance (Li et al., 2021). Moreover, the potential chemical toxicity of microplastics should not be disregarded even at low concentrations (Ranjani et al., 2021). The PHI results from this study differ from findings reported along the southeastern coast of India, where LDPE (6.27), PP (3.4), and PS (2.7) had PHI scores within the 1–10 range, corresponding to Hazard Level II (Moderate Risk) (Nithin et al., 2022). In addition, the PHI scores in this study may be comparatively lower than those reported in research conducted in China (Huang et al., 2023; Fang et al., 2019), as this study only considered the polymer and monomer hazard rankings in assessing chemical risk. A more comprehensive hazard evaluation of microplastic contamination should account for additional environmental and biological factors. These findings also contrast with the ecological risk index reported in a biofloc system used for tilapia (Oreochromis

Table 1. Polymer hazard index (PHI)

Polymer	Monomer	Percentage (%), Pn	Hazard score, Sn (Lithner, at al, 2011)	Polymer hazard index (PHI)	Hazard category	Risk category
Polietilena Tereftalat	Asam tereftalat and etilen glikol	33.3	4	1.33	II (1–10)	Medium
Polyethylene	Etilena	25	11	2.75	II (1–10)	Medium
Polivinil Klorida	Vinil klorida	16.7	10.55	1.76	II (1–10)	Medium
Polypropylene	Propilena	8.3	1	0.08	I (< 1)	Minor
Polystyrene	Stirena	8.3	30	0.08	III (10-100)	Minor

niloticus) aquaculture, where PHI values ranged from 122.966 to 212.665, indicating a high hazard level (Deswati et al., 2025).

Impact of microplastic distribution on fish species in the Musi River

Analysis of the coefficient of microplastic impact (CMPI) in ten fish species from the Musi River revealed that fragment-type microplastics exerted the highest impact, with CMPI values ranging from 0.48 to 0.87, placing them in the maximum to extreme impact categories for most species. Species such as Pangasius sp. and C. inermis showed the highest vulnerability to fragment-type microplastics, with CMPI values of 0.87 and 0.77 respectively. Meanwhile, film-type microplastics were classified within the moderate impact category, with relatively stable CMPI values across most species, reflecting their moderate distribution and bioavailability. In contrast, fiber and pellet-type microplastics had lower and inconsistent impact levels across species, with many species showing no exposure to these types at all (Table 2).

These findings suggest that the composition and types of microplastics significantly influence exposure levels and the potential ecological impact on fish species in the Musi River. Moreover, the health effects of microplastic ingestion in fish are profound and multifaceted. This study highlights that microplastics can adsorb persistent organic pollutants (POPs), which are toxic to fish and can negatively impact growth, development, and overall health (Oza et al., 2024). Chronic exposure may also lead to the bioaccumulation of toxic substances in fish tissues, posing risks not only to aquatic organisms but also to humans who consume these fish (Khan et al., 2020).

Health risk assessment

One of the widely accepted approaches for assessing the human health risk of microplastic exposure is the toxicity hazard quotient (THQ), a quantitative method used to evaluate exposure levels and their potential adverse effects (Naz et al., 2025; Lin et al., 2024). To determine non-carcinogenic indicators, data were collected from 96 respondents through structured interviews. Based on the previously described formula, the following parameters were used: EF (exposure frequency): 365 days/year, ED (exposure duration): 30 years for adults, IR (ingestion rate): average fish consumption in Palembang (52.4 grams/person/day), C (microplastic concentration in fish): 12.6 mg/kg, WAB (average body weight): 58 kg, ATn (averaging time for non-carcinogens): 365 × 30 = 10,950 days. The estimated daily intake (EDI) was calculated at 11.3 mg/kg/day. Using this, the THQ for general health risks from consuming microplastic-contaminated fish was determined to be 0.569. Based on risk assessment standards, a THQ value below 1 indicates that health risks associated with consuming microplastic-contaminated fish are considered low. This result aligns with several previous studies assessing the health effects of consuming microplastic-contaminated fish. A study by Pramaningsih et al. (2023) also found low THQ values for marine fish consumption in Indonesia, indicating health risks remain within acceptable limits. Similarly, Ding et al. (2023) reported that although microplastics were

Table 2. Microplastic impact coefficient (CMPI) on Musi River fish species

Fish species	Fragment		Film		Fiber		Pellet	
	CMPI	Category	CMPI	Category	CMPI	Category	CMPI	Category
K. Bicirrhis	0.55	Maximum	0.39	Average	0.06	Minimum	-	-
B. Schwanenfeldii	0.52	Maximum	0.28	Average	0.16	Average	0.04	Minimum
C. Inermis	0.77	Maximum	0.23	Average	-	-	-	-
M. Singaringan	0.50	Average	0.35	Average	-	-	0.15	Average
O. Vittatus	0.64	Maximum	0.33	Average	-	-	-	-
Mystus	0.64	Maximum	0.18	Average	0.18	Average	-	-
R. Argyrotaenia	0.50	Average	0.50	Average	-	-	-	-
H. Nemurus	0.50	Average	0.21	Average	0.29	Average	-	-
P. Polyurandon	0.48	Average	0.30	Average	0.22	Average	-	-
Pangasius sp.	0.87	Extreme	0.13	Average	-	-	-	-

present in freshwater fish, the associated human health risks were still classified as low according to THQ calculations.

The THQ has several limitations in health risk assessment, primarily due to its simplistic approach and limited ability to capture the complexity of chemical exposure and toxicological effects. One of the main limitations is the assumption of a linear relationship between exposure level and toxic effects, which does not always reflect real-world conditions. In addition, THQ typically evaluates risk based on average daily exposure without accounting for individual susceptibility or differences in exposure pathways (Berhanu et al., 2024; Yap and Al-Mutairi, 2022). This method also often excludes cumulative or synergistic effects of multiple contaminants, potentially resulting in less accurate overall risk assessments, especially when dealing with complex mixtures of pollutants (Tanimu et al., 2023; Yap and Al-Mutairi, 2022). However, some studies have warned that even if current THQ values remain below risk thresholds, long-term exposure to microplastics may increase the potential for bioaccumulation in the human body. The cumulative nature of risks associated with microplastic consumption may contribute to adverse health effects, even at low THQ values. This underscores the need for an integrated approach to risk assessment and environmental health strategies that take into account the complex interactions of microplastics within ecosystems (Agbekpornu and Kevudo, 2023).

Microplastics have the capacity to adsorb various hazardous organic pollutants, which may elevate health risks over time. Factors such as polymer type, shape, and chemical additives may also influence their toxicity to organisms (Masud and Cable, 2023). Furthermore, research has shown that fish feeding strategies significantly influence microplastic consumption levels. For instance, filter-feeding species exhibit higher rates of microplastic ingestion in accordance with the concentration of microplastics in their aquatic environment, as demonstrated by the findings of Conowall et al. (Conowall et al., 2024). Additionally, Zhang et al. observed that the feeding behavior of juvenile fish strongly influences their ingestion patterns, further complicating our understanding of microplastic impacts across different species (Zhang et al., 2023). Koongolla et al. documented substantial variation in microplastic accumulation associated with fish species, body size, and habitat type, suggesting that behavioral adaptations may play a role in mitigating the risks posed by these pollutants (Koongolla et al., 2022). The high concentration of PET polymers in the Musi River highlights the urgent need for companies located along the riverbanks that utilize PET materials to implement stricter waste monitoring and treatment systems to prevent microplastic release into the environment. Moreover, the public should be encouraged to reduce the use of plastic containers and packaging, particularly those made from PET, and to switch to more environmentally friendly alternatives such as glass, stainless steel, or biodegradable materials.

CONCLUSIONS

This study provides clear evidence of microplastic contamination in various fish species inhabiting the Musi River in Palembang, with *Barbonymus schwanenfeldii* identified as the most affected species. Fragment-shaped and black-colored microplastics were the most prevalent, with an average abundance of 12.6 particles per fish in the intestines and particle sizes ranging from 0.1 mm to 5 mm. Several polymer types were detected, including PET, PE, and PVC, which were classified as medium-risk based on the PHI, while PP and PS were categorized as low-risk polymers. These findings reflect the complexity of microplastic pollution and the ecological risks it poses. While the health risks to humans from consuming contaminated fish remain relatively low, the results emphasize the importance of continued monitoring and research into the long-term impacts of microplastic exposure. Addressing this environmental challenge requires a comprehensive strategy, including stricter plastic waste management policies, public education, and sustained scientific investigation.

Acknowledgments

The authors would like to thank the Director of the Health Polytechnic of the Ministry of Health of the Republic of Indonesia in Palembang who has provided internal grant funding assistance based on the Director's Decree Number DP.04.03/F.XL/1297/2024 and to the Chemistry Laboratory Team of the Environmental Health Department of the Palembang Health Polytechnic, and gratitude is also expressed to the laboratory team of the Bhakti Pertiwi College of Pharmacy, Palembang, for their assistance in conducting Fourier Transform Infrared Spectroscopy (FTIR) analysis for this study.

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