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ORIGINAL RESEARCH ARTICLE

Health risk assessment and microplastic pollution in streams through accumulation and interaction by heavy metals

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ABSTRACT

BACKGROUND AND OBJECTIVES: The threat posed by microplastics to humans through fish consumption is potentially great due to microplastics' capacity to adsorb heavy metals. The Code and Gajahwong streams have suffered from plastic and heavy metal pollution as the major rivers in Yogyakarta, Indonesia. However, little is known about the cumulative danger caused by the association of the microplastic and heavy metals. A thorough analysis of the extent of the health risks that people who consume fish from these rivers may experience is urgently needed. Hence, this study aimed to study microplastic pollution accumulated by fish in Code and Gajahwong streams, analyze the interactions with heavy metals, and assess the potential health risks.

METHODS: Fish sample collection was conducted in three stations by considering the severity of plastic pollution. Microplastics were extracted from the gills, digestive tract, muscle, and water and then characterized based on the number, size, shape, color, and type of polymer. Potential health risks were evaluated based on the potential ecological risk index, polymer hazard index, pollution load index, estimated daily intake, target hazard quotient, total target hazard quotient, and target cancer risk.

FINDINGS: Microplastics have contaminated the streams and fish and were dominated by small-sized green fibers and low-density polyethylene polymer. The pollution was related to human activities around the streams. The highest accumulation in fish was found in the digestive organs. Lead and cadmium have been associated with microplastics. The calculation of the potential ecological risk index and polymer hazard index showed that the medium risk of microplastic contamination in both streams. Based on the values of estimated daily intake, target hazard quotient, total target hazard quotient, and target cancer risk, short-term consumption of fish from the streams carries a low risk, but it will increase over time and pose a serious harm in the long term.

CONCLUSION: Given that most of the microplastics found were associated with lead and cadmium, they can increase the risk to human health due to the transfer of microplastics through food chains. Mitigation efforts involving various stakeholders, community involvement, and continuous education must be continuously pursued. This study significantly contributes to the current problem of environmental pollution by means of microplastic threats associated with heavy metals and provides a thorough health risk assessment applicable to other rivers and mitigation efforts that must be exerted to achieve sustainability.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
77	9	6

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INTRODUCTION

The consumption of plastics in modern life is unavoidable. The use of plastics for public needs is considered efficient and practical given that plastics are strong and water resistant but still light and relatively cheap (Andrady and Neal, 2009). A sharp rise in plastic waste has been observed (Jambeck *et al.,* 2015). If plastics are broken down to smaller particles known as microplastics (MPs), with sizes ranging from 0.1 µm to 5 mm, the issues caused by plastic waste can be considerably aggravated (Vriend *et al.,* 2021). Plastic degradation may develop due to water currents, exposure to solar radiation (Frias and Nash, 2019), high temperatures, and mechanical abrasion by sediments (GESAMP, 2016). MP particles composed of polyethylene (PE), low-density PE (LDPE), high-density PE (HDPE), and polypropylene (PP) can adsorb heavy metals (HMs) (Rochman *et al.,* 2014). The capability of MPs to adsorb these HMs may substantially raise potential health risks. Based on previous research, fish accumulate MPs, especially in digestive organs, such as the intestines (Wootton *et al.,* 2021), and respiratory organs, including gills (Adji *et al.,* 2022). MP contamination in fish can be caused by the small size of MPs and their varying shapes and colors, which allow them to be ingested by fish (Browne *et al.,* 2008); fish accumulate MPs unintentionally because they are hard to distinguish from food (Li *et al.,* 2021). Fibers that are shaped like cloth strands have a relatively greater distribution capability than fragments, which have an irregular and rigid shape. Fibers are also often ingested by small fish when eating or hunting (Rebelein *et al*., 2021). Irregularly shaped fragments may have secondary movements that typically slow the vertical settling velocities and cause slower sinking than MPs with other shapes but comparable sizes (Yan *et al.* 2021). Within a specific size range, MPs can be absorbed into the bloodstream. They can be translocated to muscles, which tend to be eaten by other organisms in the food chain cycle (Godoy *et al.,* 2019); as a result, bioaccumulation and biomagnification potentially increase (Tosetto *et al.,* 2017). MPs associated with HMs can cause health problems for organisms, such as a decrease in their immunity to cause infertility (Al Muhdar *et al.,* 2021). For that matter, Code and Gajahwong Streams are classified as major streams in the Special Region of Yogyakarta, Indonesia. Most areas around the flow of the two streams are densely populated with various domestic and industrial activities; thus, the waste from these activities may contaminate stream waters in Code (Widodo et al., 2013) and Gajahwong Streams (Winata and Hartantyo, 2013). The dominance of plastic wastes, such as plastic bottles, plastic bags, wrappers of various daily products, and textile waste, along the Code and Gajahwong Streams is a source of MPs in these waters (Utami *et al*., 2021). According to Widagda *et al.* (2020), Code and Gajahwong Streams experienced severe pollution levels from 2013 to 2019. This finding was confirmed by the discovery of considerable amounts of organic and inorganic wastes, which exacerbated the water quality along the stream basin. On the other hand, people around the two streams catch fish from these water bodies for consumption (Priyambodo, 2010). Research evaluating MP contamination and its relationship to HMs in the streams is still limited. A previous study examined the impact of organic pollutants on soil and water quality (Widagda *et al.,* 2020; Salam *et al.,* 2019) and confirmed the presence of MPs in fish (Sulistyo *et al.,* 2020); a comprehensive assessment is urgently needed to investigate the issue of MP pollution. The research on associations of MPs and HMs in reservoirs has been conducted by Adji *et al.* (2021) and Rahmayanti *et al.* (2022), whereas no study reported streams that cross densely populated areas. This research assessed the impact of MP pollution on fish and water in Code and Gajahwong Streams. The main focuses were to evaluate the interactions between MPs and HMs, particularly lead (Pb) and cadmium (Cd), and determine any possible health risks associated with the consumption of fish contaminated with MPs and HMs. HMs were analyzed because they are prioritized in stream water quality monitoring, according to the national regulations in Indonesia. Pb and Cd are two of the ten chemical pollutants of major public health concern due to their toxicity levels and potential to trigger cancer (WHO, 2023). More specifically, characterization of MPs was carried out to determine their color, type, and size. This study characterized polymer types with Fourier transform infrared spectroscopy (FTIR). Structural analysis and spectra of the metals adsorbed onto the surface of MPs were determined by energy-dispersive scanning electron microscopy (SEM-EDS). The associations of MPs and HMs in water samples and intact fish muscle were then determined by calculating the polymer hazard index (PHI), pollution load index (PLI), potential ecological risk index (PERI), estimated daily intake (EDI), target hazard quotient (THQ), total THQ (TTHQ), and target cancer risk (TR) to assess the risk due to MP contamination in aquatic ecosystems (Adji *et al.,* 2022; Rahmayanti *et al*., 2022). This study hypothesized that MPs have polluted water and fish from Code and Gajahwong Streams. The level of MP pollution is related to the intensity of human activity around the stream's watershed, as shown the studies conducted by Babel *et al*. (2022) and Lin *et al.* (2021), which revealed that human activity is the main factor affecting MP pollution levels. MP accumulation in fish and water is dominated by small-sized MPs, and the highest accumulation of MPs is found in the digestive organs of fish (McNeish *et al*., 2018). HM association occurs due to HM adsorption onto the MP surface, which may increase HM concentrations (Naqash *et al*., 2020). Based on PHI, PLI, and PERI calculations, the risk of MP contamination in Code and Gajahwong Streams is potentially moderate. Based on the EDI, THQ, TTHQ, and TR, fish in Code and Gajahwong Streams are considered safe for consumption within a short period. This study is expected to give comprehensive information regarding MP contamination in fish and waters of the two streams and can be used as a reference to formulate policies in efforts to manage streams and conserve water resources. These study results may also be expected to be a reference in determining the quality standards for MPs and HMs in rivers. Public and community awareness regarding river flow pollution due to littering habit is expected to be enhanced through this research. Increased environmental awareness of the public is also expected to encourage more waste reduction activities in Code and Gajahwong Streams. The current study aimed to evaluate MP accumulation by fish in Code and Gajahwong Streams, analyze MP interactions with HMs (lead and cadmium), and assess the potential health risks. This study was carried out in Code and Gajahwong Streams in 2022.

MATERIALS AND METHODS

Study area

Code and Gajahwong Streams are in the Province of Special Region of Yogyakarta, Indonesia. The streams cross Sleman, Yogyakarta, and Bantul Regencies. The total population has reached more than 4 million people and is predicted to increase significantly in the next several years (CBSPSRY, 2022). In 2022, the volume of waste produced was 1,133.94 tons/day (Bappeda, 2022). Sampling was conducted from March 2022 to June 2022 at six sampling stations (Fig. 1), which were selected based on the population density around the stream basin. Each station was selected based on fishing activity. Stations of Code (C1; 7°39'31.1"S,110°23'48.2"E) and Gajahwong (G1;7°41'34.0"S,110°24'54.4"E) Streams were selected due to the relatively low-density population around them. Thus, the levels of plastic pollution at the following stations were expected to be lower than those of other stations. Stations C2 (7°44'43.6"S,110°22'37.5"E) and G2 (7°46'57.4"S,110°23'48.8"E) were located at the center of Yogyakarta City, with the area around these stations being settlements with dense populations. Based on visual observations, the levels of waste pollution at these stations were relatively higher than those at stations C1 and G1. Stations C3 (7°52'46.8"S,110°23'34.1"E) and G3 (7°52'35.3"S,110°23'45.1"E) are entry points for Code and Gajahwong Streams to Opak Stream. Fishing activities at stations C3 and G3 are relatively high than those at other stations given that the fairly wide riverside and calm water flow are very suitable fishing spots. Stations C3 and G3 are also close to residential areas.

Sample collection

Fish were collected randomly using fishing rods and nets at each station (n = 10). The samples were stored in a 1 L ziplock bag and placed in a cool box filled with ice (Asare *et al.,* 2018). In the laboratory, the samples were kept in a refrigerator at -20 °C until further analysis. The fish were dissected to obtain their gills, muscles, and digestive tract (GIT). The organs were washed with distilled water, dried, and weighed to obtain the wet weight, and they were used to extract MPs. Analysis of Pb and Cd was carried out on the muscles, and for HM analysis, the muscles were dried in an oven at 60 °C until constant weight to obtain the dry weight. Surface water was collected randomly at the same station as fish sampling (n = 3) using a 1 L water sampler and transferred to a 1000 mL glass bottle (Asare *et al.,* 2018; McNeish *et al.,* 2018; Adji *et al.,* 2022). Glass bottles filled with water samples were immediately closed to prevent contamination. Samples were stored in a cooler and brought to the laboratory for sample extraction.

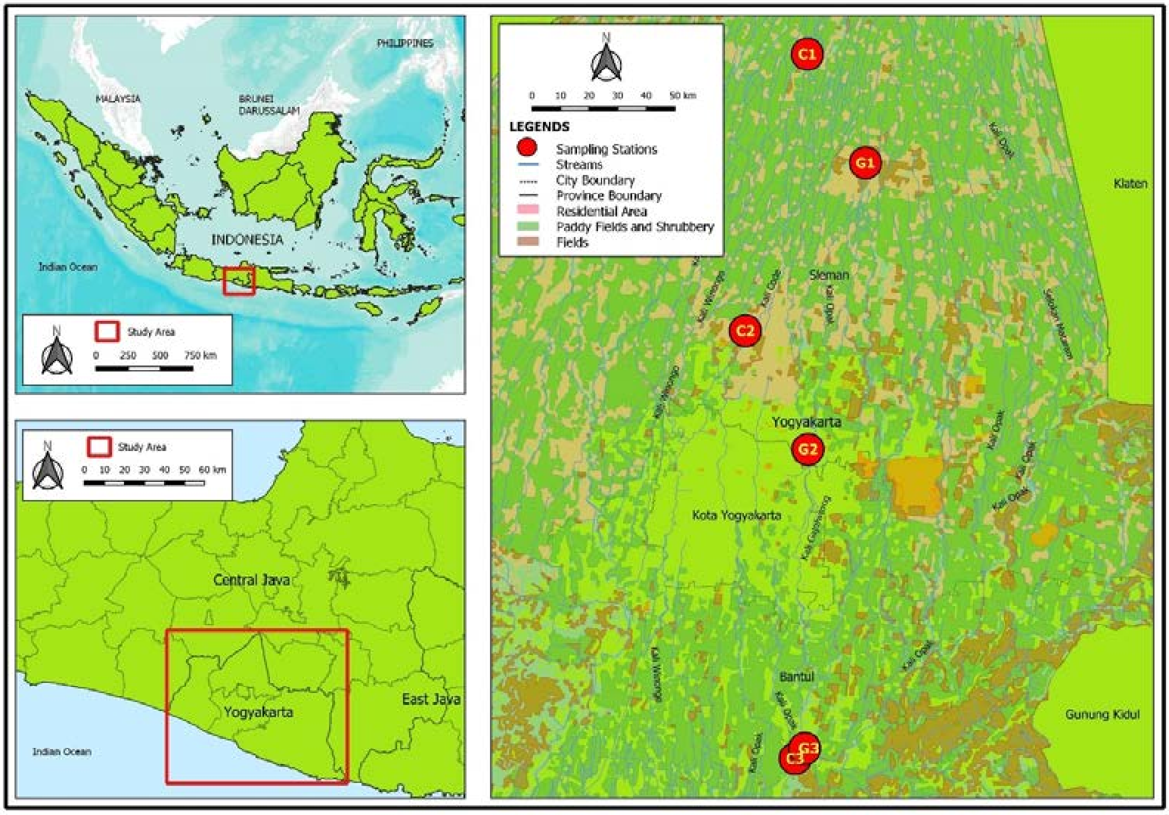


Fig. 1: Geographic location of the study area along with the sampling stations in Code and Gajahwong Streams

Extraction of MPs

The extraction of MPs in fish organs, i.e., the gills, muscles, and GIT, was performed in accordance with the work of Adji *et al.* (2022). The organs were placed in a 50 mL Erlenmeyer flask (Pyrex), and 10% potassium hydroxide (KOH) was added to the flask until the organs were submerged in the KOH solution. Next, the sample was dried in an oven for 24 h at 60 °C. After extraction, the sample was filtered with a 0.45 µm filter paper (Whatman™, UK). Each filter paper was placed in a petri dish and labeled to observe MPs in the sample. Next, water extraction was carried out by filtering with a filter paper. Again, the paper was placed in a petri dish and labeled for MP observation in the sample. During field sampling, laboratory preparation, and analysis of MPs, attention was given to quality control (QC) and quality assurance (QA). The probability of MP contamination during extraction was analyzed using the filter paper of the control (n=10). During field data collection, the sample petri dish was immediately closed and always kept in a closed condition to prevent contamination of MPs from the air. The equipment used for sample preservation was rinsed with distilled water filtered with a 0.45 µm filter paper.

Characterization of MPs

Physical characterization of MP particles was carried out by measuring the length of each particle referring to the work of Adji *et al.* (2022). MPs were classified as small if they were less than 1.5 mm, moderate if the particle size was from 1.5 mm to 3.3 mm, and large if they measured more than 3.3 mm. The color and shape MPs were also observed (Li *et al.,* 2021), i.e., fiber, fragments, films, and pellets. This observation was performed using a microscope (Leica DM 100) and Image Raster 3. The determination of MP polymer was carried out by FTIR analysis (Nicolet iS10). The particles used in FTIR analysis were selected randomly, with adjustment of the number, size, and diversity of particles among samples. SEM-EDS (Jeol-JSM-

Table 1: QC measurements for FAAS

Parameters	Units	Pb	Cd
Blank filters	µg/L	0.006±0.0001	0.006±0.0001
Blank filtrate	µg/L	0.02±0.01	0.01±0.00
Reference values	µg/L	2.00±0.01	1.50±0.03
Measured value	µg/L	1.95±0.1	1.57±0.05
Recovery	%	97.55	105.23

6510LA) analysis was also carried out to determine the surface characteristics of selected MP particles from water and fish muscle samples. This analysis was also conducted to identify the association between MPs and HMs by showing the adsorption of HMs to MPs (Kim *et al.* 2022).

Determination of HMs

Analysis of HMs Pb and Cd in fish muscle was conducted referring to the method of Asare *et al.* (2018). The samples (dry weight: 0.2 g) were mashed with a pestle and mortar and placed in a 50 mL Erlenmeyer flask (Pyrex). Then, 5 mL concentrated H_2SO_4 (Merck) and 10 mL concentrated HNO_3 (Merck) were added, and the mixture was heated on a hotplate at 130 °C for 20 min. Afterward, the sample was filtered with a 0.45 µm filter paper in a 50 mL volumetric flask (Pyrex) and added with bidistilled water up to the mark. HM contents (Pb and Cd) were determined using a flame atomic absorption spectrometer (FAAS). The detection limits for Pb and Cd were 0.5 and 0.1 mg/L, respectively. The HM concentration was expressed as µg/g. HMs adsorbed onto the surface of MPs were analyzed using a weak acid extraction. The MP particles were placed in a 50 mL Erlenmeyer flask, added with 10 mL 10% HNO_3, and left for 2 h at 30 °C. The sample was filtered with a 0.45 µm filter paper in a 50 mL volumetric flask (Pyrex) and added with distilled water up to the mark. To ensure the correctness of measurement procedure, a calibration curve was created using standard solution concentrations (Titrisol®, Germany) and compared it with standard calibration measurements (certificate number: SN.115–028/ILS/IV/2021). Blank solutions were defined to ensure that each analysis meets QA and QC. Table 1 describes the blank solution measurements.

Assessment of health risks

PHI was calculated by referring to the research of Ranjani *et al.* (2021). It was computed using Eq. 1 to determine ecological hazard through the toxicity of MP polymer types (Ranjani *et al.* 2021).

$$\mathrm{PHI} = \Sigma \mathrm{Pn} \times \mathrm{Sn} \quad (1)$$

According to the formula proposed by Meng *et al.* (2023), ratio of MPs abundance to MPs minimum abundance at each sampling point (CFi) is the ratio of MP abundance (Ci) to MP minimum abundance (Coi) at each sampling point.

PLI shows the level of MP pollution in Code and Gajahwong Streams. The mathematical model was used to calculate the PLI value using Eqs. 2 and 3 (Meng *et al.*, 2023).

$$\mathrm{CFi} = \frac{\mathrm{Ci}}{\mathrm{Coi}} \quad (2)$$

$$\mathrm{PLI} = \sqrt[n]{\mathrm{CFi}} \quad (3)$$

The MP CFi describes the quotient between the MP concentration at each station (Ci) and the minimum MP concentration (Coi).

PERI is a parameter for assessing the ecological hazard category caused by MP contamination. In this study, PERI value was calculated through the model proposed by Ranjani *et al.* (2021) in Eqs. 4, 5, and 6.

$$C_f^i = C^i / C_n^i \quad (4)$$

$$T_f^i = \sum_{n=1}^{n} \frac{P_n}{C^i} \times S_n \quad (5)$$

$$E_r^i = T_r^i \times C_f^i \quad (6)$$

Next, calculations were conducted for the EDI of MP and HM samples. The EDI of MP extraction samples was calculated based on a mathematical formula introduced by Barboza *et al.* (2020) (Eq. 7), whereas that of HMs was calculated in accordance with the work of Salam *et al.* (2020) using Eq. 8 for the average body weight (61.4 kg) and consumption rate (130 g/day/individual) (Adji *et al.*, 2022).

EDI MP = MP particles (particles/g) × consumption rate (g/d/individual) (7)

$$\text{EDI HM} = \frac{\text{HM concentration}\left(\frac{\mu g}{g}\right) \times \text{Consumption rate}\left(\frac{g}{d}\right)}{\text{Weight (kg)}} \quad (8)$$

THQ was calculated using Eq. 9 (Salam *et al.* (2020).

$$\text{THQ} = \frac{\text{EF} \times \text{ED} \times \text{FIR} \times \text{C}}{\text{RfD} \times \text{WAB} \times \text{TA}} \times 10^{-3} \quad (9)$$

The EF represents the frequency of exposure (156 days/year, assuming three fish meals per week). ED is the exposure period (70 years, with a lifetime of 70 years), and FIR is the level of food consumption (130 g/day/ for Indonesian adults (Firmansyah *et al.*, 2019). C represents the content of HMs in fish muscle (µg/g wet weight), WAB denotes the average weight (NCD-RisC, 2020), and TA indicates the average period of exposure to non-carcinogens (365 days/year×ED). The RfD states the reference dose of each HM, and the RfD values for Cd and Pb are 0.5 and 4.0 /kg/day, respectively (DeForest *et al.*, 2007). Fish is declared dangerous for consumption when the THQ value exceeds 1 (Khan *et al.*, 2008). TTHQ was calculated based on the equation formula proposed by Salam *et al.* (2020) to determine non-carcinogenic health risks due to consumption of fish with more than one type of HM contamination. Eq. 10 was used for the calculation (Salam *et al.* 2020).

$$\text{TTHQ} = \text{THQ}_{\text{Cd}} + \text{THQ}_{\text{Pb}} \quad (10)$$

TR was calculated using the formula described by Salam *et al.* (2020). Carcinogenic cancer risk is determined to assess the possibility of cancer caused by certain carcinogens in a certain period. The TR was calculated using Eqs. 11 and 12 (Salam *et al.* 2020).

$$\text{TR} = \frac{\text{EF} \times \text{ED} \times \text{FIR} \times \text{C} \times \text{CSF}}{\text{WAB} \times \text{TA}} \text{X } 10^{-3} \quad (11)$$

$$\Sigma\,\text{TR} = \text{TR}_{\text{Pb}} + \text{TR}_{\text{Cd}} \quad (12)$$

Data analyses

Principal component analysis (PCA) was performed using XLStat Premium by Lumivero to evaluate the relationship between MP concentrations, fish species, and sampling stations.

RESULTS AND DISCUSSION

MPs in water

Analysis of MPs in the water samples showed that MPs have contaminated the waters of Gajahwong and Code Streams at all sampling stations (Fig. 2).

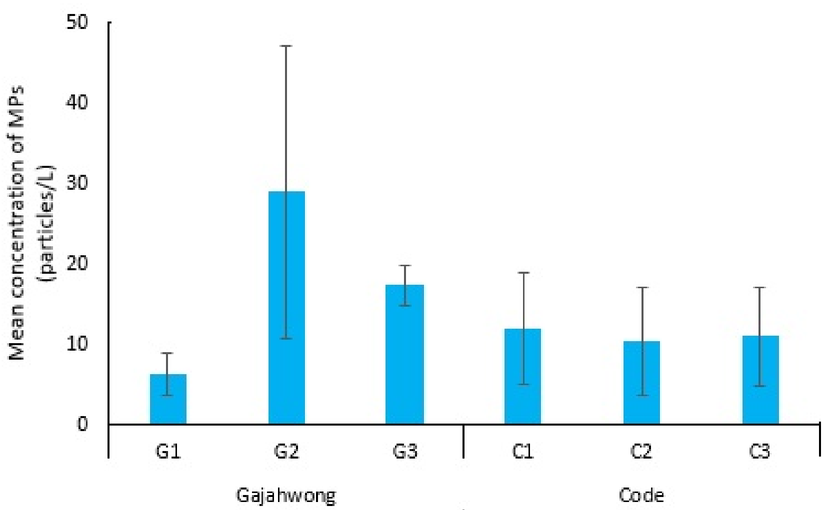


Fig. 2: Concentration of MPs in the waters of Gajahwong and Code Streams

The highest MP contamination was observed at stations G2 (Gajahwong Stream) and G3, with MP concentrations reaching 29 ± 18.19 and 17.3 ± 2.51 particles/L, respectively. The highest concentration observed at station G2 may be due to its location, that is, around residential areas and fishing activities. This notion was supported by the map of sampling stations (Fig. 1), which demonstrated that station G2 is near downtown Yogyakarta, which is a densely populated area. The station receives plastic waste from resident activities. After station G2, a floodgate can inhibit the distribution of MPs. Station G3, which is the entry point from Gajahwong Stream to Opak Stream and is relatively wider compared with other stations, may receive more materials from upstream. The station is also a fishing spot for the local community. The mean concentrations of MPs in Code Stream water significantly differed between the three stations (C1, C2, and C3), with values of 12 ± 7, 10.33 ± 6.65, and 11 ± 6.08 particles/L, respectively. Stream water with the lowest average concentration of MP contamination was found at G1 with a MP concentration of 6.33 ± 2.51 particles/L (Palupi, 2022).

The concentrations of MPs in the waters of Gajahwong and Code Streams were relatively lower compared with other streams, such as Surabaya River (Lestari *et al.,* 2021), Citarum River (Ali *et al.,* 2021), and three other streams in Southeast Asia (Babel *et al.*, 2022). However, the values are still relatively higher than those of the inlet and outlet networks of Rawa Jombor Reservoir (Rahmayanti *et al.*, 2022), several streams in Chicago, United States (McCormick *et al.,* 2016), and Ottawa Stream in Canada (Vermaire *et al.,* 2017). These studies were conducted in urban areas. Still, several factors can cause heterogeneity in the concentration of MPs that contaminate streams; such factors include population density (Mani *et al.,* 2015), human activities around stream basins (Kataoka *et al.,* 2019), the presence of dams (Watkins *et al.,* 2019), and wastewater treatment systems (McCormick *et al.,* 2016). The study's results regarding the concentration of MPs in Code and Gajahwong Streams (Fig. 2) showed a fluctuating trend, one of the reasons being the difference in population density around the stations. According to the Central Bureau of Statistics for the Special Region of Yogyakarta (2022), in two years (2020–2022), the population has increased to more than 100,000 residents. The increased population density of Yogyakarta has added to the intensity of human activities around the two streams, such as household activities, fishing (Sulistyo *et al.,* 2020), and public facilities in tourist areas (Zaman *et al.,* 2021). In this study, fibers were the dominant form of MPs contaminating Gajahwong and Code Streams (Fig. 3). The MPs found at stations G2 and three stations of Code Stream were 100% fiber, whereas at stations G1 and G3, the percentage of fragments accounted

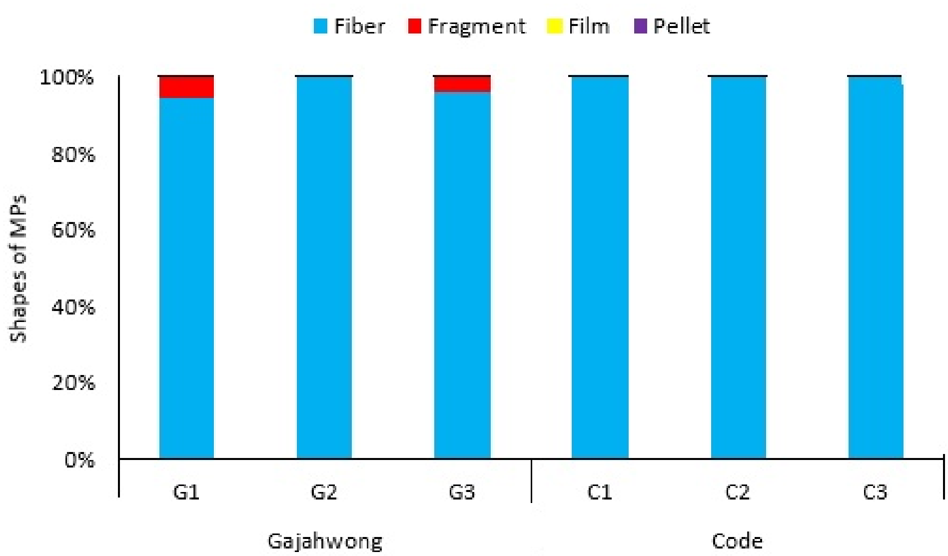


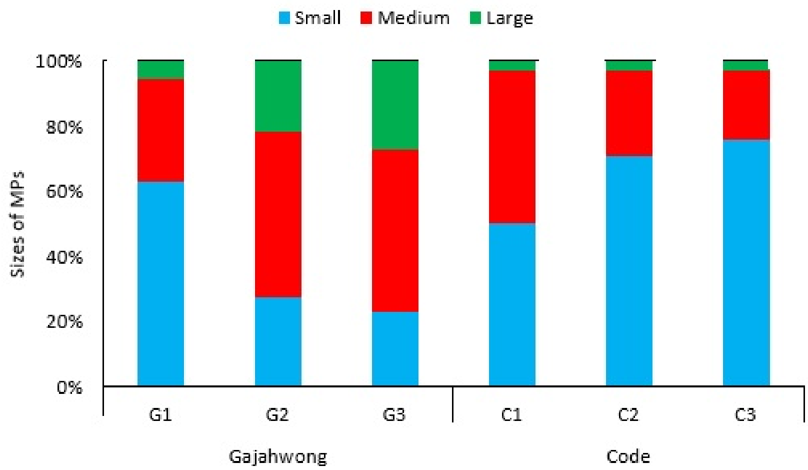
Fig. 3: Shape of MPs found in the waters of the three stations of Gajahwong and Code Streams

for approximately 5%. Similar results were reported by Su *et al*. (2019), who observed that MP fiber dominated the stream waters. Fiber contamination can be caused by the high intensity of human activities, which can produce wastes in the form of fiber; these activities include fishing with fishing rods or fishing nets (Basri *et al.,* 2021), washing clothes (Yang *et al.,* 2021), and waste production from household clothing or the textile industry (Alam *et al.,* 2019). Different results have been reported for Code and Gajahwong Streams (Utami *et al*., 2021) and three other streams in Southeast Asia (Babel *et al*., 2022), with findings indicating that fragments can also dominate the streams. According to Clere *et al.* (2022), fibers are relatively more flexible than fragments; thus, the former are more easily carried away by water currents and more difficult to get stuck or deposited. Rahmayanti *et al*. (2022) also reported different results; film-shaped MPs dominated the waters compared with fibers and fragments. This finding proves that the type of MP is greatly influenced by the type of waste that pollutes waters.

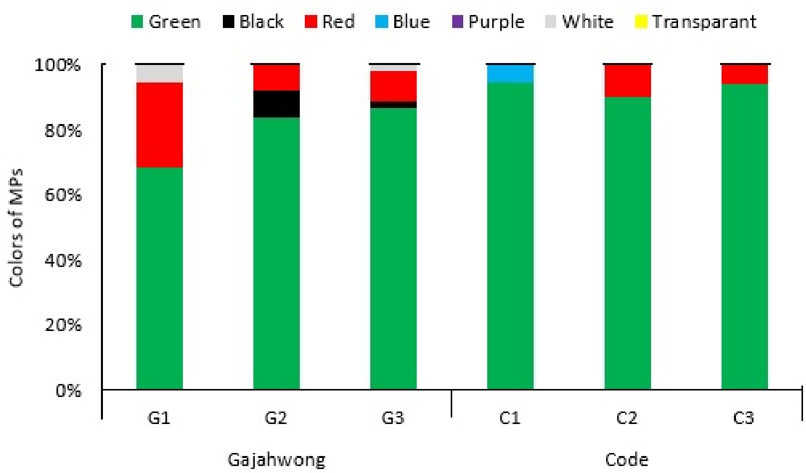
The constituent polymers also influence the distribution of MPs given that each polymer has a different density; thus, the type of polymer affects the buoyancy of MP particles (Wu *et al.,* 2018). Polymers, such as PE and PP, have a relatively low density compared with other polymers, i.e., 0.91–0.96 gram per cubic centimeters (g/cm^3) for PE and 0.90 g/cm^3 for PP (Andrady, 2017); therefore, both polymers float easily and are carried away by water. The results of FTIR analysis showed that the MP particles in the water samples from the two streams were dominated by LDPE, a copolymer of PE. About 5.26% and 3.84% of the particles at stations G1 and G3 were fragments with LDPE polymer, respectively. Most of the plastic waste found in both study areas were bottles, plastic bags, and other product packaging. According to GESAMP (2015), PE and PP are primary raw materials for product packaging; given their relatively short shelf life, they will be disposed of as waste relatively quickly. Bordos *et al.* (2019), Liu *et al.* (2021), and Garcés-Ordóñez *et al.* (2022) also showed the dominance of PE and PP in MP contamination in various aquatic ecosystems. MPs are formed as a result of plastic degradation physically, chemically, or biologically (Andrady, 2017; GESAMP, 2015); therefore, various factors, such as the duration of MPs carried by stream currents, the distance traveled by MPs, and intensity of ultraviolet radiation affect, the size of MP particles (GESAMP, 2016). In this study, the percentage size of MPs varied among stations (Fig. 4). Stations C2 and C3 were dominated by small MPs (<0.5 mm), with percentages reaching 70.97% and 75.76%, respectively (Palupi, 2022), whereas in Gajahwong Stream, small MPs dominated station G1 with the percentage reaching 63.16%. Different results were shown at stations G2 and G3; medium-sized MPs dominated the two stations at 50.57% and 50%, respectively. The results of this study regarding the percentage size of MPs (Fig. 4a) showed a different trend between Gajahwong and Code Streams. This trend can determine which station plastic waste enters the stream. The dominance of small MPs that pollute the waters was also reported by He *et al*. (2021). The high percentage of small-sized MPs indicated that streams carried plastic waste from long distances or for a long time given the long period required to degrade plastics into small sizes. As shown in Fig. 4a, the activity of garbage disposal by residents may be relatively high at stations G2 and G3, with the percentages of prominent MPs at these stations reaching 21.84% and 26.92%, respectively, which were considerably higher than those of other stations, in which large MPs accounted for less than 6%. In this study, MP particles that contaminated stream water had various colors, i.e., green, black, red, and blue (Fig. 4b). Green color dominated the MPs found in all stations (70%–90%).

MPs in fish

MP contamination was found not only in the water but also in six species of fish found in the two streams (Fig. 5). Small particles dominated MP contamination in the organs of each species (<1.5 mm); with this size, MPs can easily contaminate fish being eaten by other fish and enter the filtration process in gills (Jabeen *et al.,* 2017). The average concentrations of MPs in the GIT were relatively higher compared with those in gills and muscles. The dominance of green MPs (Fig. 4b) in stream waters can lead to an increase in MP contamination in the digestive organs of fish given the similarity of green MPs, especially fiber MPs, to microalgae or phytoplankton. The green color causes difficulty for herbivorous fish to distinguish between microalgae and MPs. The color of MP particles also affects the fish's ability to select their food. Predatory fish species that rely on their visual abilities to find



(a)



(b)

Fig. 4: (a) Size and (b) color of MPs found in waters at the three stations of Gajahwong and Code Streams

prey can be confused by MP particles that have a color resembling that of their prey (de Sa *et al.*, 2015). MP contamination in muscles is the result of absorption of MPs through the blood; thus, the MP particles can be spread in the muscles (Aryani *et al.*, 2021); MPs also contaminate gills, which are the respiratory organs of fish, and enter through these sites incidentally when fish swim; MP particles can contaminate fish muscles if they are absorbed into the blood vessels of fish, either through the digestive or respiratory tract (Su *et al.*, 2019; Jaafar *et al.*, 2021; Makhdoumi *et al.*, 2021; Adji *et al.*, 2022).

Barbodes binotatus, which lives in Gajahwong Stream, had the highest level of MP accumulation compared with other species. In Code Stream, the highest accumulation of MPs was found in *Nemacheilus fasciatus, Rasbora lateristriata,* and *Barbodes binotatus* (Palupi, 2022). *Barbodes binotatus* (Situmorang *et al.*, 2013), *Rasbora lateristriata* (Djumanto and Setyawan, 2009), and *Nemacheilus fasciatus* (Elinah *et al.*, 2016) are omnivores and feed on the same type of food. In this study, other species,

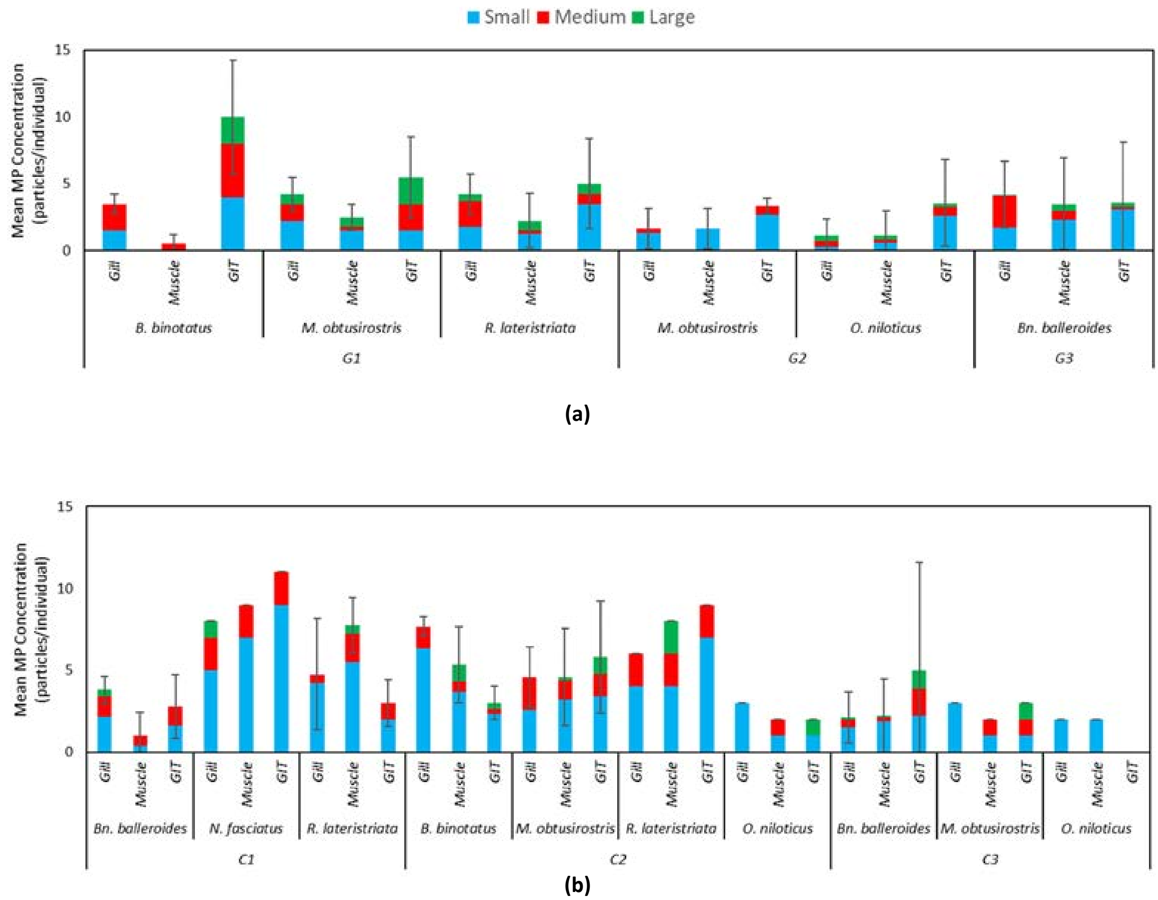


Fig. 5: Concentrations of MPs found in fish at the three stations of (a) Gajahwong and (b) Code Streams based on particle size.

namely, *Barbonymus balleroides*, *Mystacoleucus obtusirostris*, and *Oreochromis niloticus*, were also contaminated by MP particles but at relatively lower values than the three previous species. *M. obtusirostris* is an omnivore but shows carnivorous tendencies given its preference for animals, such as worms, zoobenthos, or insects, compared with algae or aquatic plants (Djumanto *et al.,* 2014). *M. obtusirostris* is less attracted to green MP particles. This species can still be contaminated with MPs if it preys on other contaminated fish. *B. balleroides* and *O. niloticus* are omnivores but tend to become herbivores (Temesgen *et al.,* 2022); thus, the chance of contamination between fish species is relatively lower than that between other species. Wu *et al.* (2021) confirmed that herbivorous fish species more easily consume MPs that resemble phytoplankton or plant litter; thus, the concentrations of MPs in herbivorous fish species can increase. According to Mizraji *et al.* (2017), omnivorous fish species contain more MP than herbivorous or carnivorous fish species. This finding is caused by a wider food source for omnivorous species, such as zooplankton and benthos organisms contaminated with MPs, which can potentially cause bioaccumulation in fish (Adji *et al.,* 2022). In this study, fiber was the most common type of MP found. The most dominant MP colors were green and black (Fig. 6a and 6b, respectively). Transparent MP fragment types were also found in this study (Fig. 6c).

In this study, green, black, and red fibers were the most abundant MP particles detected in fish bodies (Fig. 7). The dominance of green MP particles in the fish body can indicate the tendency of fish to eat microalgae. The black and red MPs can confirm that several fish species were omnivores and mistook MPs as prey.

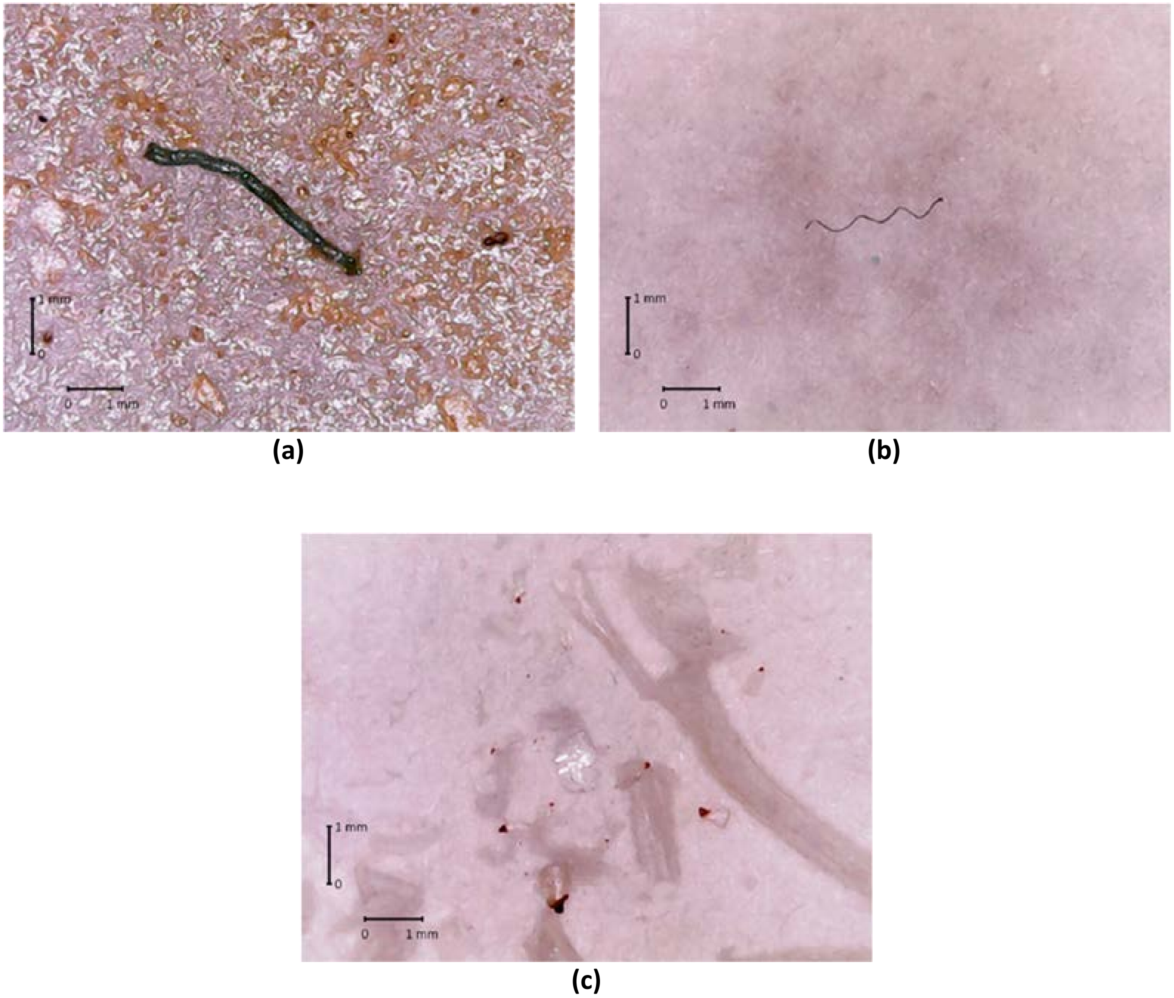


Fig. 6: MP particles in the form of (a) green fibers, (b) black fibers, and (c) transparent fragments observed during the study

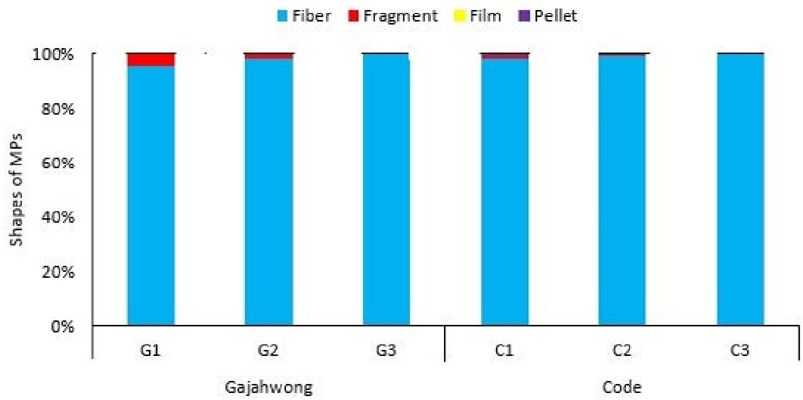
Principal component analysis

PCA showed that components F1, F2, and F3 produced eigenvalues of more than 1 (Fig. 8). In addition, F4 and F5 had eigenvalues of 0.58 and 0.35, respectively (Fig. 8a). The biplot construction in the following study used components F1 and F2 given that the eigenvalues of the two components indicate a significance between data.

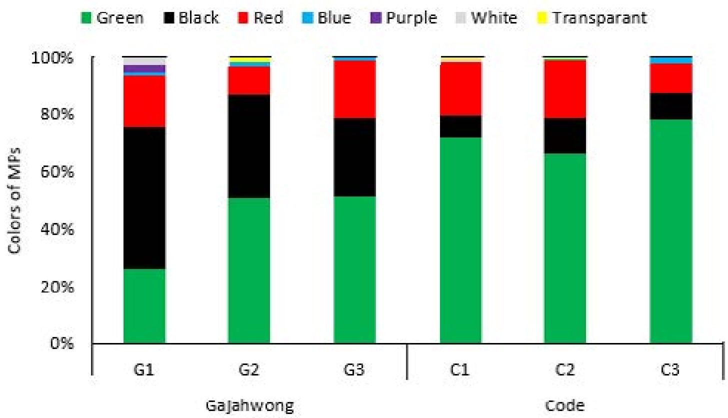
The results of biplot construction in the following study showed a variation of 81.49% in the research data (Fig. 8b). In the biplot, stations G1, G2, and C2 were in positive positions from the F1 axis, which indicates the high abundance of MPs in these stations. By contrast, stations G3, C1, and C3 were in the opposite position, which implied their low MP abundance. This finding showed that the concentration of MPs found in water samples was relatively lower than those that contaminated most of the fish samples. *B. binotatus, M. obtusirostris,* and *O. niloticus* were associated to stations G1 and C2, which indicated that these species are common at both stations.

Determination of HMs in water and fish muscles and their association with MPs

Pb and Cd can be detected in water samples, MPs in water, fish muscle, and MPs contaminating fish muscle (Table 2). IGR (2021) stated that the threshold



(a)



(b)

Fig. 7: (a) Shape and (b) color of MP particles contaminating fish

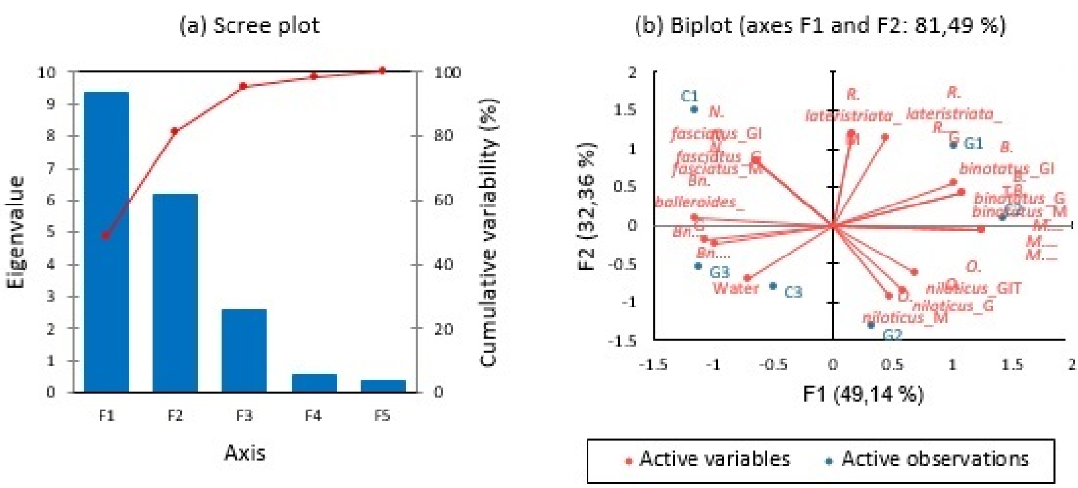


Fig. 8: (a) Scree plot and (b) biplot result of PCA of MP contamination in water and fish organs from Gajahwong and Code Streams

values for Pb and Cd in waters are 0.03 and 0.01 mg/L, respectively. In accordance with the regulation, the concentrations of HMs in the water of the two streams exceeded the threshold values. The broadest range of Pb concentrations in Gajahwong Stream waters was found at station G1 (0.25–0.40 mg/L), whereas the highest concentration of Cd was observed at station G2. In Code Stream, station C3 was the stream waters with the highest contaminations of Pb and Cd (Palupi, 2022).

The difference in the contaminations of Pb and Cd from the two streams can be caused by differences in sources of Pb and Cd. Based on the locations of streams that cross densely populated areas (Fig. 1) and field observations during sample collection, the activities and habits of the surrounding community have the potential to increase the concentrations of Pb and Cd as stream pollutants. Several activities, such as smoking, throwing electrical waste into rivers, and disposal of steel waste, are sources of Cd contamination, whereas others, such as the use of leaded fuel and leaded pipes and disposal of paint waste, also increase Pb levels in streams. HM contamination in streams or other aquatic environments that exceeds threshold values or quality standards will have direct and indirect impact on aquatic organisms (Velusamy *et al.*, 2014). HMs were also detected in MP samples from water. In Gajahwong Stream, the waters at G2 and G3 stations showed MP adsorption for Pb and Cd, respectively, whereas in Code Stream, station C3 showed adsorption for both metals (Palupi, 2022). The metals also accumulated in fish muscles, from which MPs were extracted (Table 2). *O. niloticus* in Gajahwong Stream was contaminated with Pb and Cd. Meanwhile, in Code Stream, Pb contamination in fish muscle was detected in *O. niloticus*, whereas *B. balleroides* exhibited the highest Cd contamination (Palupi, 2022). The concentration of HMs associated with the MP surface was higher than that in water samples. The results also confirmed that the range of concentrations of the two metals adsorbed by MPs in Gajahwong and Code Stream waters was higher than that of HMs in the water samples. Based on research conducted by Naqash *et al.* (2020), concentrations of HMs increased when they were adsorbed with MP particles. The effects caused by HM contamination associated with MPs are more complex. SEM-EDS observations were carried out to confirm the adsorption of HMs onto the surface of MP particles (Fig. 9). Based on the analysis, Pb and Cd were adsorbed onto the surface of MPs. The blue color

Table 2: Concentrations of Pb and Cd in water, MPs in water, fish muscle, and MPs in the muscle of fish species in Gajahwong and Code Streams

Sample		Gajahwong (G)		Code (C)	
		Pb	Cd	Pb	Cd
HMs in water (mg/L)					
Station 1		0.25–0.40	0.02–0.04	0.01–0.03	0.03–0.05
Station 2		0.27–0.31	0.03–0.05	0.03–0.05	0.03–0.04
Station 3		0.27–0.34	0.00–0.01	0.01–0.08	0.01–0.05
HMs associated with MPs in water (µg/g)					
Station 1		0.57–0.76	0.09–0.11	0.16–0.31	0.03–0.07
Station 2		0.59–1.65	0.09–0.12	0.15–0.18	0.02–0.06
Station 3		0.46–0.82	0.08–0.16	0.17–0.28	0.02–0.66
HMs in fish muscle (µg/g)					
1.	*Rasbora lateristriata*	5.10–6.61	1.18–1.55	6.13–6.50	1.09–1.60
2.	*Mystacoleucus obtusirostris*	5.08–7.32	1.18–1.87	5.79–6.91	1.35–1.48
3.	*Barbodes binotatus*	6.52–6.83	1.22–2.2	6.00	1.09
4.	*Oreochromis niloticus*	5.23–8.04	1.11–2.37	6.27–10.75	1.29–1.37
5.	*Barbonymus balleroides*	5.70–6.94	0.99–2.36	5.06–6.69	1.19–1.83
HMs associated with MPs in fish muscle (µg/g)					
1.	*Rasbora lateristriata*	0.02	0.05	0.09–0.68	0.07–0.09
2.	*Mystacoleucus obtusirostris*	0.06–0.25	0.03–0.05	0.11–0.67	0.08–0.13
3.	*Barbodes binotatus*	0.07	0.06	0.18–0.55	0.10–0.15
4.	*Oreochromis niloticus*	0.09	0.03	0.66	0.07
5.	*Barbonymus balleroides*	0.42–0.58	0.12	0.45–0.72	0.08–0.13
6.	*Nemacheilus fasciatus*	N/A	N/A	0.06	0.07

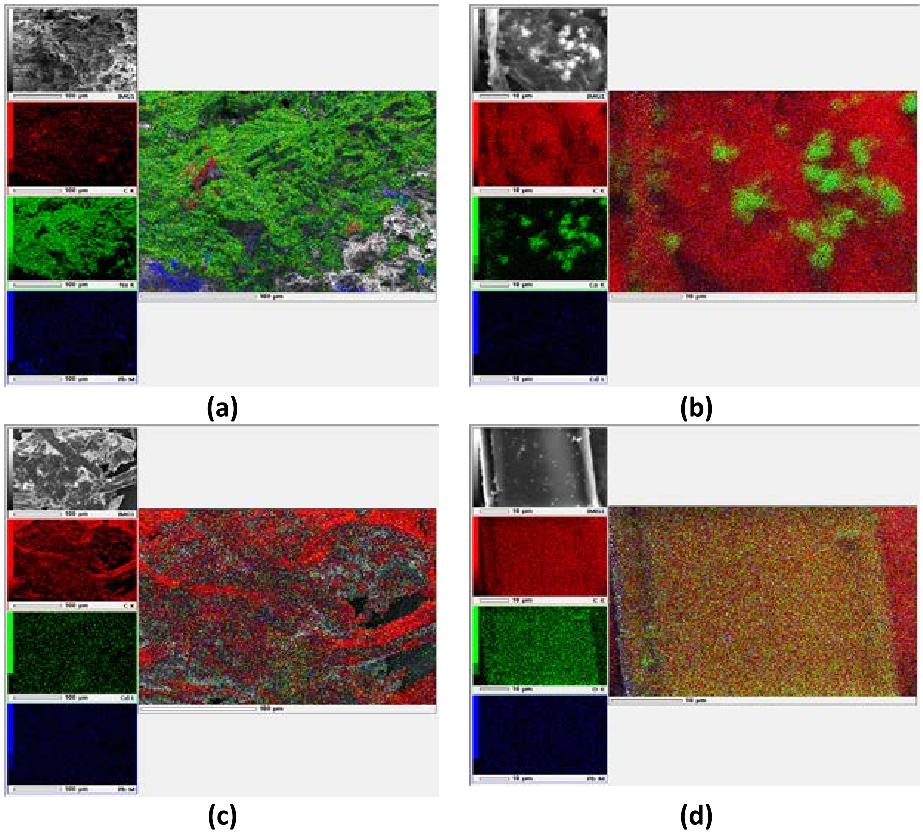


Fig. 9: SEM-EDS of MP samples in (a) Code Stream's water, (b) muscles of fish from Code Stream, (c) Gajahwong Stream's water; (d) muscles of fish from Gajahwong Stream

denotes the adsorption of Pb on MP samples in Code Stream water (Fig. 9a) (Palupi, 2022). Meanwhile, Cd accumulation onto the surface of MP in fish muscles was also marked in blue (Fig. 9b). The adsorption of Pb in the MP samples from Gajahwong Stream water was indicated by a blue color. By comparison, Cd was marked in green (Fig. 9c). Meanwhile, the accumulation of Pb onto the surface of MP in muscles of fish from Gajahwong Stream was evidenced by a blue color (Fig. 9d).

Assessment of health risks

The dominance of PE as a polymer composing MP particles has led to the two streams having level II and I hazard based on the PHI and PLI, respectively, whereas based on the PERI, Gajahwong and Code Streams had a medium level of risk (Table 3). The level of hazard and risk at the six stations was based on the presence of LDPE. Thus, the existence of other polymers may significantly affect the results of these calculations.

The highest PHI was observed at station G2 and all stations in Code Stream, where all stations had level II hazard. The highest PLI was detected at station G2. Meanwhile, the highest PERI was recorded at station G2, and all stations in Code Stream had the same value, i.e., 173.77 (Palupi, 2022). The six research stations had a medium-category risk level. However, this level did not rule out the possibility of high MP contamination in the area. The fish species sampled at the station were classified as small fish. This finding increases the potential threat because small fish have been contaminated at medium levels. Through food chains, fish consumption may also lead to biomagnification. Biomagnification incidents are possible and may have dangerous and complex consequences. As a carrier of HMs, biomagnification of MP contamination may lead to malnutrition

Table 3: PHI, PLI, and PERI and their hazard and risk levels at six stations

Stations	PHI	Hazard level	PLI	Hazard level	PERI	Risk categories
G1	8.61	II	3.56	I	165.62	Medium
G2	9.09	II	7.62	I	173.77	Medium
G3	8.74	II	5.89	I	167.09	Medium
C1	9.09	II	4.90	I	173.77	Medium
C2	9.09	II	4.55	I	173.77	Medium
C3	9.09	II	4.69	I	173.77	Medium

Table 4: MP and HM EDI in Code and Gajahwong Streams

Stream	Species	MPs (particles/day/individual)	HM on fish muscle (µg×kg/day)		HM on muscle's MPs (µg×kg/day)	
			Pb	Cd	Pb	Cd
Gajahwong	*Barbodes binotatus*	190.98	14.13	3.62	0.15	0.13
	Barbonymus balleroides	46.77	13.57	3.00	1.06	0.25
	Mystacoleucus obtusirostris	116.98	13.53	2.88	0.30	0.08
	Oreochromis niloticus	73.55	13.54	3.05	0.19	0.06
	Rasbora lateristriata	409.59	12.06	2.86	0.04	0.11
Code	*Barbodes binotatus*	125.55	12.70	2.31	0.77	0.26
	Barbonymus balleroides	100.51	12.63	2.93	1.24	0.20
	Mystacoleucus obtusirostris	90.82	13.57	3.03	0.89	0.23
	Nemacheilus fasciatus	2800.00	0.00	0.00	0.13	0.15
	Oreochromis niloticus	31.57	18.02	2.82	1.40	0.15
	Rasbora lateristriata	774.89	13.39	2.79	0.83	0.17

(Roman *et al*., 2020), increased oxidative stress, behavioral abnormalities (Naqash *et al*., 2020), neurotoxicity, decreased enzymatic activity (Barboza *et al*., 2020), and cancer (Cox *et al*., 2019).

The daily human intake (EDI) in Code and Gajahwong Streams varied depending on the species (Table 4). The highest EDI in MP samples of fish in Gajahwong Stream was observed in *R. lateristraiata*. Meanwhile, *N. fasciatus* showed the highest EDI in Code Stream (Palupi, 2022). *B. binotatus* had the highest HM contamination of Pb and Cd in the muscle of fish sampled in Gajahwong Stream, whereas *B. balleroides* exhibited the highest HM contamination associated with MPs (Palupi, 2022). In Code Stream, *O. niloticus* had the highest Pb content in fish muscle, whereas Cd presented the highest muscle content in *M. obtusirostris.* For the association of HMs with MPs, the highest concentration of Pb was observed in *O. niloticus*, and that for Cd was noted in *B. binotatus* (Palupi, 2022). These results were higher than those of seafood consumed by individuals in America (106–126 particles/day/individual) (Cox et *al.,* 2019). Complex digestion processes and continuous and dynamic habitats can cause variations in contamination values in fish. According to the Indonesian National Standard (SNI) 7387:2009 for the maximum limit of HM contamination in food, the limit for Cd contamination in the fish category and its processed products is 0.1 mg/kg. By contrast, in the same category, the limit value for Pb is 0.3 mg/kg. Suppose that the sample's EDI exceeds the acceptable daily intake (ADI). In such case, harmful effects can occur in humans due to consumption of contaminated products. Based on the results obtained, no samples had an EDI exceeding the ADI. Thus, consumption of these fish from Code and Gajahwong Streams is not potentially hazardous to health. However, the consumption of contaminated

Table 5: THQ, TTHQ, and TR HMs in fish muscle due to consumption of fish from Code and Gajahwong Streams

Stream	Species	HM on fish muscle					
		THQ (10^{-3})		TTHQ (10^{-3})	TR		∑TR
		Pb	Cd		Pb	Cd	
Gajahwong	*Barbodes binotatus*	1.51	3.09	4.60	5.13x10^{-5}	9.74x10^{-3}	9.79x10^{-3}
	Barbonymus balleroides	1.45	2.56	4.01	4.93 x10^{-5}	8.07x10^{-3}	8.12x10^{-3}
	Mystacoleucus obtusirostris	1.45	2.46	3.91	4.91 x10^{-5}	7.77x10^{-3}	7.80x10^{-3}
	Oreochromis niloticus	1.47	2.61	4.05	4.92 x10^{-5}	8.21x10^{-3}	8.25x10^{-3}
	Rasbora lateristriata	1.29	2.45	3.74	4.38 x10^{-5}	7.71x10^{-3}	7.75x10^{-3}
Code	*Barbodes binotatus*	1.38	1.98	3.33	4.61 x10^{-5}	6.21x10^{-3}	6.26x10^{-3}
	Barbonymus balleroides	1.35	2.51	3.85	4.59 x10^{-5}	7.88x10^{-3}	7.92x10^{-3}
	Mystacoleucus obtusirostris	1.45	2.59	4.04	4.92 x10^{-5}	8.15x10^{-3}	8.20x10^{-3}
	Nemacheilus fasciatus	0.00	0.00	0.00	0.00 x10^{-5}	0.00x10^{-3}	0.00x10^{-3}
	Oreochromis niloticus	1.93	2.41	4.33	6.55 x10^{-5}	7.58x10^{-3}	7.64x10^{-3}
	Rasbora lateristriata	1.43	2.39	3.82	4.86 x10^{-5}	7.51x10^{-3}	7.56x10^{-3}

Table 6: THQ, TTHQ, and TR association of HM and MPs in fish muscle due to consumption of fish from Code and Gajahwong Streams

Stream	Species	HM associated MPs in muscle					
		THQ (10^{-3})		TTHQ (10^{-3})	TR		∑TR
		Pb	Cd		Pb	Cd	
Gajahwong	*Barbodes binotatus*	0.02	0.11	0.12	5.38x10^{-7}	3.42x10^{-4}	3.43x10^{-4}
	Barbonymus balleroides	0.13	0.22	0.33	3.85x10^{-6}	6.84x10^{-4}	6.88x10^{-4}
	Mystacoleucus obtusirostris	0.03	0.07	0.09	1.09x10^{-6}	2.11x10^{-4}	2.12x10^{-4}
	Oreochromis niloticus	0.02	0.05	0.08	6.92x10^{-7}	1.71x10^{-4}	1.72x10^{-4}
	Rasbora lateristriata	0.01	0.09	0.09	1.54x10^{-7}	2.85x10^{-4}	2.85x10^{-4}
Code	*Barbodes binotatus*	0.09	0.23	0.31	2.81x10^{-6}	7.13x10^{-4}	7.15x10^{-4}
	Barbonymus balleroides	0.13	0.17	0.30	4.49x10^{-6}	5.36x10^{-4}	5.40x10^{-4}
	Mystacoleucus obtusirostris	0.09	0.12	0.29	3.22x10^{-6}	6.27x10^{-4}	6.30x10^{-4}
	Nemacheilus fasciatus	0.01	0.13	0.14	4.62x10^{-7}	3.99x10^{-4}	4.00x10^{-4}
	Oreochromis niloticus	0.15	0.13	0.28	5.08x10^{-6}	3.99x10^{-4}	4.04x10^{-4}
	Rasbora lateristriata	0.08	0.15	0.23	3.00x10^{-6}	4.56x10^{-4}	4.59x10^{-4}

products will cause detrimental effects if consumed excessively and continuously in the long term.

The highest TTHQ of Pb and Cd was observed in *B. binotatus* muscle samples from Gajahwong stream. By contrast, in Code stream, *O. niloticus* and *M. obtusirotris* had the highest THQ for Pb and for Cd, respectively (Table 5) (Palupi, 2022). The highest TR due to contamination of the two metals in Gajahwong Stream was observed in *B. binotatus* and in *M. obtusirotris* in Code Stream. For HM associations and MPs in fish muscle, the highest TTHQ was detected in *B. balleroides* for both metals in Gajahwong Stream. Meanwhile, *B. binotatus* attained the highest TTHQ for both metals in Code Stream (Table 6) (Palupi, 2022). For the TR values, *B. binotatus* had the highest potential value due to contamination of the two metals in Gajahwong Stream, whereas *M. obtusirotris* attained such result in Code Stream (Palupi, 2022). Determination of THQ for Pb and Cd in muscle samples (Table 5) and muscle MP and HM associations (Table 6) revealed that all values were lower than 1. These results indicated that the potential for harm caused by fish consumption decreased. For both HMs, the TTHQ were less than 1 for all fish species, which implies that the species from Code and Gajahwong Streams are safe for consumption. If the TR value is less than 10^{-4}, it is considered safe against cancer risk. Meanwhile, if the TR value is in the interval of 10^{-3}–10^{-4}, it is considered to have not met the standard. If the value is greater than 10^{-3}, the contamination can pose a significant potential risk of cancer (Salam *et al.*, 2020). In this study, the concentration of HMs in fish muscle samples in both streams showed a less safe value. Meanwhile, the accumulation of HMs on the surface of MPs in all fish species found in both streams was considered safe. This finding needs attention because fish in both streams may also be exposed to toxicants besides HMs. The comprehensive evaluation showed that the long-term impacts caused by environmental pollution are complex and disastrous. Uncontrolled

MP pollution in streams affects water and fish quality, which increases the risk to human health. These major streams flow into the Indian Ocean (Fig. 1). If this pollution occurs continuously without any concrete mitigation measures, it will expand MP contamination and cause a systematic impact on marine ecosystems. Mitigation action involving several stakeholders must be carried out immediately by improvising waste collection, reducing disposal activities, and tightening the regulations of waste production as an effective strategy.

CONCLUSION

MPs have been confirmed to have moderately polluted the Code and Gajahwong Stream waters. These locations have relatively the same level of MP pollution, given the characteristics of the watershed and their location in a densely populated area. MPs in the waters indicate that plastic degradation processes have occurred along the two streams. The primary source of MP pollution is waste disposal by people who less awareness of environmental sustainability. As a result, fish that live in the streams are also contaminated with MPs. MPs polluting the waters and those accumulated by fish mainly include small-sized, green, and fiber-shaped MPs consisting of LDPE polymer. These characteristics cause difficulty among fish to distinguish MPs as food or waste. Thus, avoiding the accidental consumption of MPs is difficult. The MPs found were associated with HMs (Pb and Cd). Pb and Cd are priority HMs to be assessed in water quality assessment and may trigger cancer. The adsorption of HMs with MPs causes the concentration of HMs to increase significantly due to the increased surface area of MPs, as shown by the results of plastic degradation. In this case, *Rasbora lateristriata* and *Oreochromis niloticus* were found to accumulate significant amounts of MPs. Both types of fish are consumed by the local community, which thereby increases health risks. Although the accumulation of HMs tested is not yet at an alarming level, in the long term, health risks can be faced by people consume these fish from the streams. The research on MP pollution and its association with HMs in relation to health risk assessment is still limited. Recent studies on the capability of MPs as adsorbents pique interest because they are not only associated with HMs but also organic pollutants, such as hydrocarbons or pesticides. This phenomenon offers great opportunities for future MP research. Exposure to MPs as an adsorbent that can absorb various kinds of pollutants is presumed to have a negative impact on fish body systems histologically, biochemically, and physiologically, although further research still needs to be conducted to study the long-term effects of this pollution. Researchers are recommended to address knowledge gaps in the understanding of cumulative exposure toxicity of MPs and various pollutants to fish and humans. This research significantly contributes to the recent issue of environmental pollution and environmental risk assessment in freshwater ecosystem by means of the danger of MP associated with HMs and provides a thorough health risk assessment and mitigation efforts that must be taken to achieve sustainability. Sustainable plastic waste management is needed as a comprehensive interdisciplinary framework to address the complex problem of plastic waste management. Increasing the scope of plastic waste management and services and their efficiency are prerequisites for the improvement of environmental quality. The involvement of various related parties is needed to formulate good policies regarding the management of stream ecosystems. Mitigation efforts including various stakeholders, community involvement, and continuous education must be continuously pursued. This study is expected to be used as a scientific basis to assist the authorities in making policies regarding the management and control of pollution in river ecosystems and as a strong reference for conducting similar research to assess the potential risk of MP pollution.

AUTHOR CONTRIBUTION

A.M. Sabilillah performed sample collection, extraction, and characterization of MPs. F.R. Palupi conducted the determination of HMs and assessment of health risks. B.K. Adji interpreted research results and prepared the map of sampling stations. A.P. Nugroho supervised the project and contributed to managing and developing research ideas, verifying research methods, and reviewing the manuscript. All authors provided critical feedback and helped shape the research, analysis, and manuscript.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. The ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been completely witnessed by the authors.

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PUBLISHER'S NOTE

ABBREVIATIONS

µg/g	Microgram per gram
Mm	Micrometer
%	Percent
°C	Degree Celsius
ADI	Accepted Daily Intake
C	HM content in fish muscle
C1	Code Station 1
C2	Code Station 2
C3	Code Station 3
Cd	Cadmium
Ci	Concentration of MPs at each station
Cfi	Ratio of MPs abundance to MPs minimum abundance at each sampling point
Coi	Background MPs concentration
CSF	Oral carcinogenic slope factor
ED	Period of exposure
EDI	Estimated daily intake
EF	Exposure frequency
Eq	Equation
F	The features in dataset (X)
Fig	Figure
FIR	Food Ingestion Rate
FT-IR	Fourier transform infrared spectroscopy.
G	Gram
G1	Gajahwong Station 1
G2	Gajahwong Station 2
G3	Gajahwong Station 3
g/cm^3	Gram per cubic centimeters
GIT	Gastrointestinal tract
H_2SO_4	Sulfuric acid
HDPE	High-density polyethylene
HM	Heavy metals
HNO_3	Nitric acid
i.e.	Id Est (that is)
Kg	Kilogram
Kg/day	Kilogram per day
KOH	Potassium hydroxide
L	Liter
LDPE	Low-density polyethylene
mg/kg	Milligram per kilogram
mg/L	Milligram per liter
mL	Milliliter
Mm	Millimeter
MPs	Microplastics
N	Entire quantity
Particles/l	Particles per liter
Pb	Lead

PCA	Principle Component Analysis
PE	Polyethylene
PERI	Potential ecological risk index
PHI	Polymer hazard index
PLI	Pollution load index
Pn	Percent of specific types of polymers in each sampling station
PP	Polypropylene
QA	Quality assurance
QC	Quality control
RfD	Reference dose of individual HMs
SEM-EDX	Scanning electron microscopy-energy-dispersive x-ray spectroscopy
Sn	Hazard score of MP polymers
SNI	Indonesian National Standard
TA	Mean period of exposure to non-carcinogens
THQ	Target hazard quotient
TLV	Threshold limit value
TR	Target cancer risk
TTHQ	Total target hazard quotient
WAB	Mean weight

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